



V. T A T A R I N O V

HUMAN  
ANATOMY  
AND PHYSIOLOGY

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**TO THE READER**

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## INTRODUCTION

Anatomy and physiology are biological sciences dealing with living organisms.

*Anatomy* is the science of the structure of living organisms. Human anatomy studies the form and structure of the human body and its various organs, for example, those of the bones, muscles, heart, brain, spinal cord, etc. The term "anatomy" comes from the Greek word *anatomē* meaning dissection, which indicates one of the methods used in the study of the structure of organisms.

*Physiology* is the science of the processes operating in living organisms. It studies the functions of the organism, the activities of its different organs, for example, the work of the muscles, heart, brain, spinal cord, etc. The term "physiology" comes from two Greek words: *physis*—nature, and *logos*—word.

Anatomy and physiology are intimately connected. The structure of the living organism and its vital activities, in other words its forms and functions, are inseparable and interdependent. This statement may be confirmed by the structure and functions of various organs of the human body: the structure of the lungs is connected with the function of gas exchange, that of the kidneys, with the formation of urine, that of the stomach, with the digestion of food, etc. It follows that the structure of the organism and its various organs must be considered in relation to their functions.

Anatomy and physiology are closely associated with many other branches of biology, in particular *histology* (from the Greek word *histos* meaning tissue), the science of the tissues forming the organs, and *embryology*, the science of the embryonic development of the organism. The science of the changes occurring in a diseased organism is also closely connected with anatomy and physiology. This science is called *pathology* (from the Greek word *pathos* meaning disease). There are two branches of pathology; *pathologic anatomy* and *pathologic physiology*.

The principle of the integrity of the organism and its unity with its external environment must always be used when studying anatomy

and physiology, and the other biological sciences. All organs of the living organism are interconnected; they continuously interact and make up a common, complex system. The organism is also closely connected with the conditions of its existence, i.e., its external environment. According to I. Pavlov, the activities of the organism continuously adapt themselves to changes in its surroundings and there is an "equilibration between the organism and the external environment".

\*   \*  
\*   \*

Anatomy and physiology are core subjects in a medical curriculum. Without knowledge of normal anatomy and physiology it is impossible to understand the changes caused by disease in the various organs and the organism as a whole. It follows that knowledge of anatomy and physiology is essential for the study of any medical subject.

Thorough knowledge of the structure and functions of the organism is necessary for the prevention of disease, which is the first and foremost duty of all medical workers.

A nurse must have thorough knowledge of human anatomy and physiology if she is to care for her patients intelligently and successfully.

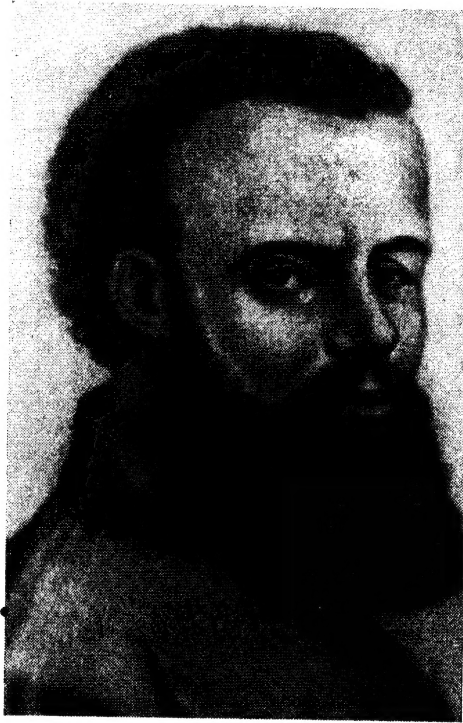
Moreover, anatomy and physiology contribute to the formation of a scientific outlook and give the student an idea of man's place in nature. A study of anatomy and physiology reveals the common origin of man and animals, and the material character of all the processes operating in the human organism.

## BRIEF HISTORY OF ANATOMY AND PHYSIOLOGY

Anatomy and physiology owe their development primarily to the needs of practical medicine. Diseases can be treated only if the structure and functions of the organism are known. Various facts in this branch of human knowledge have been accumulated over the centuries.

Even the ancients had fragmentary knowledge of anatomy and physiology, but this knowledge was neither systematic nor scientific.

There was considerable interest in anatomy and physiology, and medicine in general, in ancient Greece. The famous Greek thinker and physician Hippocrates (460-377 B.C.) contributed several works on medicine containing information on anatomy and physiology. For example, he gave a reasonably correct description of the cranial bones. Some of his concepts were wrong; he believed that the arteries contained air and that the brain was a kind of mucus.



Andreas Vesalius

The outstanding physician of the Roman Empire was Claudius Galen (130-200 A.D.). He experimented on animals and dissected their carcasses. His works mention nerves and muscles, describe seven pairs of cranial nerves, several joints, the oval opening between the atria in the foetuses of domestic animals, etc. Even so, they contain many errors in describing the structure and functions of the human organism. For example, Galen constructed an incorrect scheme of blood circulation with the liver as the central organ. His fundamental mistake was that he applied facts pertaining to the structure of the animal body to the human body without any modification.

The Middle Ages were characterized by stagnation in science, including medicine. The church suppressed science and persecuted scientists. One of the manifestations of church oppression was a categorical prohibition to dissect corpses, which greatly hindered the development of medicine. During the Middle Ages only individual scientists succeeded in making a contribution to science. One of them was the



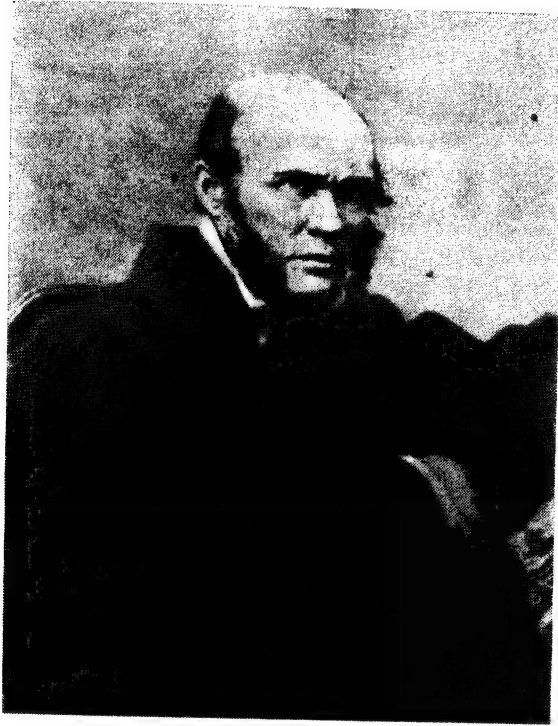


William Harvey

outstanding scientist, physician and philosopher ibn-Sina (Avicenna) who lived in 980-1037 A.D.

Avicenna's famous book *The Canon of Medicine* is a systematic encyclopaedia containing all the medical knowledge of his time, including information on anatomy and physiology.

Anatomy and physiology became specific scientific disciplines during the Renaissance in connection with the general development of natural science at the time when bourgeois society was being formed. Anatomy as an independent science dates from the 16th century. Its originator was Andreas Vesalius (1514-1564) who dissected numerous human corpses and studied the structure of the human body. His studies were summarized in the outstanding scientific work *De humani corporis fabrica* (The Structure of the Human Body) which was subsequently praised by Academician I. Pavlov who wrote: "The work of Vesalius is the first human anatomy in the modern history of man; it does not merely repeat the instructions and opinions of



Nikolai Pirogov

ancient authors, but rests on the efforts of a free, searching mind.”

Physiology as an independent science was founded in the 17th century. Its foundation is connected with William Harvey (1578-1657), the English physician who discovered the circulation of the blood. In 1927 I. Pavlov wrote about his work: “William Harvey discovered one of the organism’s greatest functions—circulation of the blood—and thus laid the foundation for a new branch of precise human knowledge, the physiology of animals.”

The subsequent development of anatomy and physiology was determined by new methods of scientific observation and by the general development of science. In the 19th and 20th centuries there were great advances in various branches of medicine, physiology in particular. These advances are in large measure due to the contributions of Russian scientists.

The first medical school in Russia was organized in the middle of the 17th century. By that time there were Russian manuals con-

taining information on medicine, and anatomy was studied from skeletons. Systematic training of medical workers, some of whom subsequently became outstanding scientists, began in the 18th century (during the reign of Peter I). The brilliant Russian scientist M. Lomonosov made a great contribution to the development of natural science and medicine in Russia. As a result of his efforts the first Russian University with a school of medicine was opened in Moscow. Lomonosov's works contain a good deal that has a direct bearing on physiology.

In the 19th century many Russian scientists were working in the fields of anatomy and physiology. The development of Russian anatomy was greatly influenced by the works of P. Zagorsky, I. Buyalsky and N. Pirogov.

P. Zagorsky (1764-1846), Professor of anatomy and physiology, studied the vascular system. He wrote a textbook of anatomy in Russian, and his pupils were the first Russian anatomists. One of them was I. Buyalsky (1789-1866), author of numerous works on anatomy and surgery. Buyalsky's most important contribution was that his works demonstrated the enormous importance of anatomy to practical surgery.

The brilliant Russian scientist N. Pirogov (1810-1881) studied surgery, anatomy and other branches of medicine. He introduced a new method of anatomical research entailing consecutive sections of refrigerated corpses. By this method he set out the fundamentals of topographic anatomy\*. One of his best known works on anatomy is his book *Surgical Anatomy of Vascular Trunks and Fasciae*. His works emphasize the importance of anatomy to practical medicine, especially surgery.

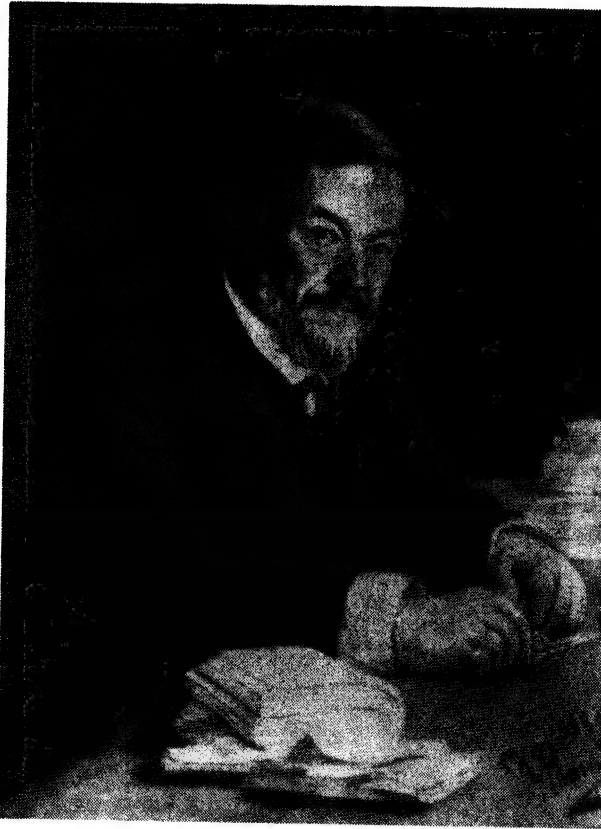
During the heroic defence of Sevastopol in 1854 Pirogov helped to organize groups of nurses and encouraged them to tend the wounded on the battlefield.

The functional trend in anatomy has risen and developed in Russia. This trend regards every organ as part of the whole—the living organism in connection with its functions and historical development.

At the same time it emphasizes the role of external environment, the influence of the conditions of life, both social and biological. Important contributions in this field were made by P. Lesgaft (1837-1909), V. Vorobyov (1876-1937), V. Tonkov (1872-1954) and many other scientists.

Among the most distinguished 19th century Russian scientists who worked in physiology are A. Filomafitsky, V. Basov, N. Miloslavsky, F. Ovsyannikov, A. Kulyabko, and S. Botkin. Some of them made

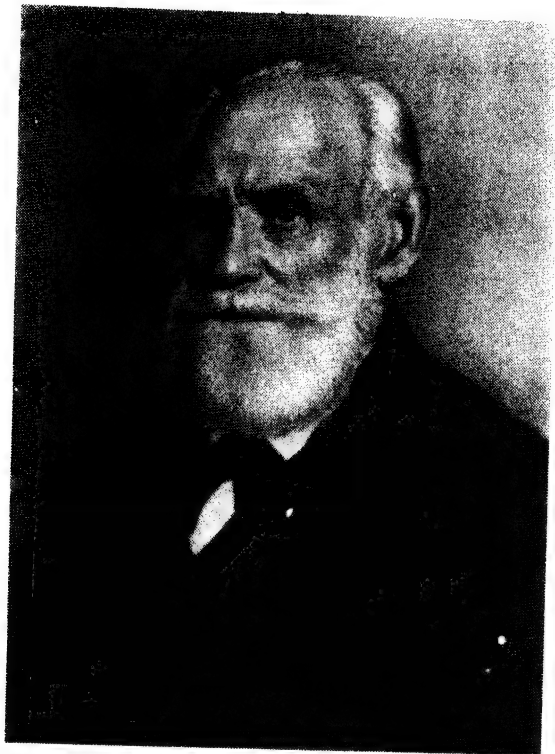
\* Topographic anatomy is an applied science which studies the interrelations of organs.



**Ivan Sechenov**

discoveries in the physiology of the blood and blood circulation, others studied the functions of digestion, still others studied respiration, the nervous system, etc. I. Sechenov and I. Pavlov made particularly important contributions to physiology.

I. Sechenov (1829-1905) was the founder of Russian physiology. He is credited with outstanding discoveries in various branches of this science; he discovered the phenomenon of inhibition in the central nervous system; he was the first to study the composition of the gases in the blood, elucidated the role and importance of haemoglobin in the transportation of carbon dioxide, etc. Sechenov's book *The Reflexes of the Brain*, published in 1863, made an exceptional contribution to the science of physiology. This work was the first to state



Ivan Pavlov

that all cerebral activity is of a reflex nature and, consequently, the mental processes inherent in man have a physiologic basis and not some unknowable cause. Sechenov was one of the originators of the principle of the unity of the organism and its environment. He wrote: "The organism without its external environment, which sustains its existence, is unthinkable; the scientific definition of the organism must therefore also include the environment which influences it..."

Sechenov founded an important school of physiologists. N. Vvedensky, M. Shatyornikov, and other noted scientists were his pupils.

I. Pavlov (1849-1936) was a brilliant materialist scientist who devoted more than 60 years of his life to physiology and made an enormous contribution to the whole of medicine and biology.

When Pavlov was still a young man his world outlook was greatly influenced by the materialist ideas of the revolutionary democrats N. Chernyshevsky, N. Dobrolyubov and D. Pisarev. Sechenov's

works, particularly his book *The Reflexes of the Brain*, also played an important part in the formation of Pavlov's views on natural science.

Pavlov, like Sechenov, based his scientific work on the principle of integrity of the organism and its unity with its surroundings. Following this principle he considered the functions of the various organs in relation to the entire organism and the external environment. Before Pavlov's time physiologists most commonly employed the analytical methods of scientific observation. Observations were usually conducted on animals in so-called acute experiments, i.e., a surgical operation was performed so that they could be studied immediately after the operation. An example of an acute experiment is the opening of an animal's thorax in order to study the work of its heart.

Pavlov developed a synthetic method based on the concept of the integrated activity of the organism. He usually made his scientific observations on animals by carrying out so-called chronic experiments. The animals were operated on in such a way that they stayed alive and could be kept under scientific observation for long periods of time (months and even years).

Pavlov made very important discoveries in various branches of physiology. His principal works were devoted to the physiology of the circulation of the blood, digestion and the activities of the cerebral hemispheres. His work on the physiology of the circulation of the blood led to the theory of regulation of cardiovascular activity.

His theory of the physiology of digestion was the result of almost 20 years of investigations into the functions of the digestive organs. He established that the activities of the organs of the digestive system are regulated by the nervous system and are dependent on various phenomena in the external environment.

Pavlov's studies brilliantly confirmed Sechenov's ideas about the reflex nature of the activity of the organism. The various stimuli from the external environment acting on the organism are perceived by the nervous system and evoke changes in the activities of the appropriate organs. These response reactions of the organism to stimuli transmitted through the nervous system are called *reflexes*.

Pavlov's research into the functions of the cerebral cortex is particularly important. His research has demonstrated that man's psychic activity is based on physiologic processes operating in the cerebral cortex. Before Sechenov and Pavlov the basis of psychic activity was unknown and was considered unknowable. The studies of the functions of the cerebral cortex, which underlie our psychic activity, became possible only after Pavlov had established that the activity of the cerebral cortex is based on the formation of conditioned reflexes (see below).

The theory of higher nervous activity developed by Pavlov is profoundly materialistic; it refutes all religious and idealistic concepts of the "soul" and of the unknowable "work of the soul".

Pavlov's theory is one of the natural science foundations of the materialist world outlook which holds that the world is objective and knowable.

The various problems of the structure and functions of human tissues and organs and of living matter are being elaborated by scientists in numerous institutes and laboratories. The characteristic feature of recent scientific research is that it is conducted on a molecular, submicroscopic and cellular level. For this purpose very fine and complex experiments and methods are used. These experiments and methods make it possible to study the processes operating inside the cell and in the various structures which form part of the cell.

The character of research is determined by the necessity of discovering the nature of all processes which underlie the vital activities, growth and development of cells and tissues in the normal organism and in different diseases (for example, malignant tumours), and of learning to control these processes.

## C H A P T E R 1

# *Cells and Tissues*

After the invention of the microscope (in the beginning of the 17th century) it became possible to study the fine structure of organisms and to examine structural details invisible to the naked eye. The very first observations with a microscope showed that plants consist of cells.

Later investigators also discerned cells in the organisms of animals. For nearly two centuries scientists collected facts which served as the basis for the cell theory, i.e., the theory of the cellular structure of organisms.

Extensive material on the microscopic structure of various tissues and organs of animals and man was accumulated. A great deal of work was carried out by the Czech scientist Purkinje and his pupils in the beginning of the 19th century.

In 1838 the German scientist T. Schwann formulated one of the basic propositions of the cell theory, namely: "All plant and animal organisms have a cellular structure." The discovery of the cellular structure of organisms has played a very important part in the development of natural science. It was highly regarded by F. Engels who considered it as great a discovery as those of the law of conservation of energy and the theory of evolution. And this is reasonable because the cell theory pointed out the common structure of the organic world, which led to the concept of a common origin, i.e., the theory of evolution.

The cell theory was one of the corner-stones of the theory of evolution devised by Darwin. It is also of great practical importance, for it provides the knowledge necessary for understanding the changes occurring in the organism in disease, and thus for developing correct medical treatment.



## CELLS

Cells are the basic form of existence of living matter. Plant and animal organisms are made up of cells. The two main constituents of cells are the cytoplasm and the nucleus.

**Plant cells** have a more or less regular form which is usually quadrangular (Fig. 1A). This is due to the fact that they have a well-defined membrane made of a special substance called cellulose. Under the membrane is the cytoplasm, with the nucleus in the centre of the cell. Plant cells also contain vacuoles or bubbles of cell juice.

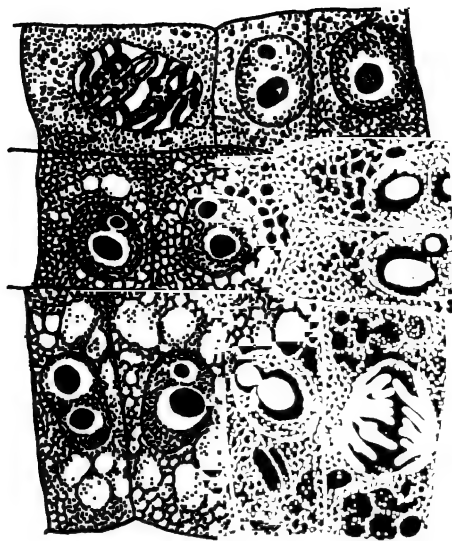
**Animal cells** vary in shape; they may be spherical, prismatic, spindly, dendritic, etc. (Fig. 1B). The membrane of animal cells is not well-defined. The nucleus is usually in the centre of the cell, but it may also lie closer to the membrane. The cells are, as a rule, of microscopic size. Only some cells are visible to the naked eye (for example, the ova of fish and amphibians).

Metabolism, irritability (the ability to respond to changes in the environment), and reproduction (division) are the basic vital properties of a cell. The complexity of its functions determines its structure and composition. Cellular matter is a colloid system of complex organic substances—proteins, fats, carbohydrates, and of water and inorganic salts. Proteins form the ground substance of the different structures of the cell and determine its basic vital properties. Fats form part of the cell membrane and mitochondria, and serve as energy-yielding material. Carbohydrates are the major source of energy which is essential for the vital processes in the cell. Water is bound with proteins and other organic substances and along with the inorganic salts accounts for the physico-chemical properties of the cell matter as a colloid. It should be noted that salts are present in the cell matter in definite concentrations and maintain a constant osmotic pressure in the cell.

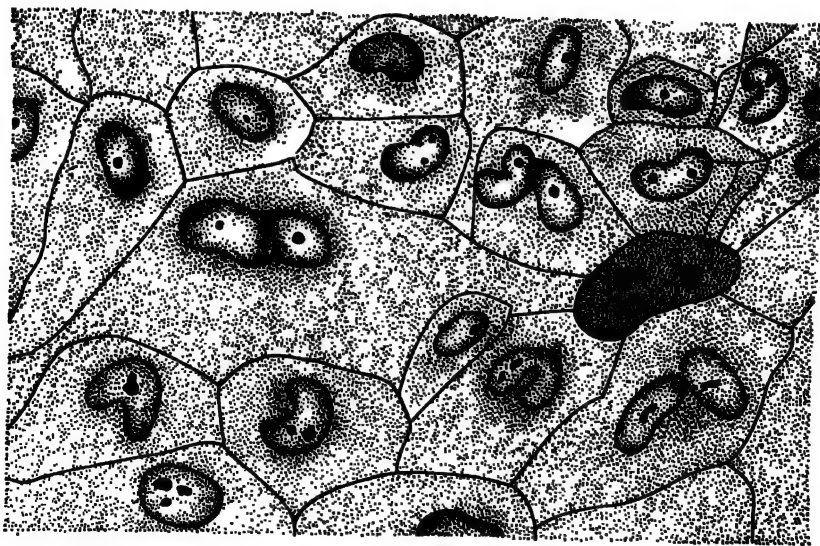
**Enzymes** are among the chief cell constituents. They are of a protein nature and serve as biological catalysts. They are responsible for metabolic processes taking place in the cells rapidly and in definite order.

Recent investigations give detailed knowledge of the structure and role of nucleic acids, desoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is found only in the nucleus, whereas RNA is found in the nucleus and in the cytoplasm. DNA is concerned in the reproduction of nucleic acids, while RNA (there are different forms of RNA) takes part in protein synthesis.

**Nucleus.** The nucleus is usually in the centre of the cell and is of a comparatively constant spherical or oval shape. It is enclosed in a porous membrane which separates it from the cytoplasm. Each nucleus contains one or two nucleoli in which the synthesis of nucleic



A



B

**Fig. 1. Plant and animal cells**

**A—plant cells; vacuoles of cell juice are seen in cytoplasm; B—animal cells (epithelium of serous membranes)**

acids takes place. Chromosomes are the chief constituents of the nucleus, which appear at the time of cell division. Chromosomes are composed of protein ground substance and DNA. Each species of organisms has a strictly constant number of chromosomes (humans have 23 pairs of them). The chromosomes carry hereditary information (transmit hereditary properties of the organism).

**Cytoplasm.** Cytoplasm is the main part of the cell substance. An ordinary light or electron microscope reveals that it contains a complex system of various fine structures. Some of them are inclusions of general occurrence and are known as *organelles* or *organoids*. Among them are the ergastoplasm (in which, in the so-called ribosomes, protein synthesis takes place), *mitochondria* (in which chemical reactions occur yielding energy for the cell), *internal reticular apparatus* (Fig. 2), *central body* or *centrosome* (which participates in the process of cell division, Fig. 3), and others. Besides organelles the cytoplasm may contain inconstant inclusions which appear in certain physiological states of the cell (e.g., grains of pigment in the cells of skin epithelium after sunburn).

The cells of specialized tissues also contain special structures depending on the specific functions of these cells (for example, the contractile myofibrils in the muscle cells).

**Intercellular substance.** In addition to cells the organism also contains intercellular substance which is not of cellular structure. *Intercellular (interstitial) substance* is present, as the name suggests, between the cells. The structure of intercellular substance varies with the functions of the tissue of which it is a constituent. Intercellular substance is developed the most in the connective tissues, especially those which perform a mechanical function. *Fibrous structures* and a homogeneous *ground substance* are distinguished in intercellular substance. Various fibres—some of low elasticity, some gelatinous (collagenous), and some elastic—are present in the ground substance, as though they were soldered into it. Metabolism takes place in all types of intercellular substance, as well as in the cells. Like the cells, these structures develop, age, disintegrate and form again. It follows that they are living structures and that they are one of the forms of existence of living matter. Intercellular substance exists in the organism only in connection with the cells, together with which it forms a living system united in its structure and activity.

**Cell reproduction.** In a living organism cells reproduce. There are two methods of cell reproduction: karyokinesis or mitosis (indirect cell division) and amitosis (direct cell division). In mitosis complex changes inside the nucleus and cytoplasm are observed before their division. In amitosis the nucleus and cytoplasm of the cell divide without any visible changes within them.

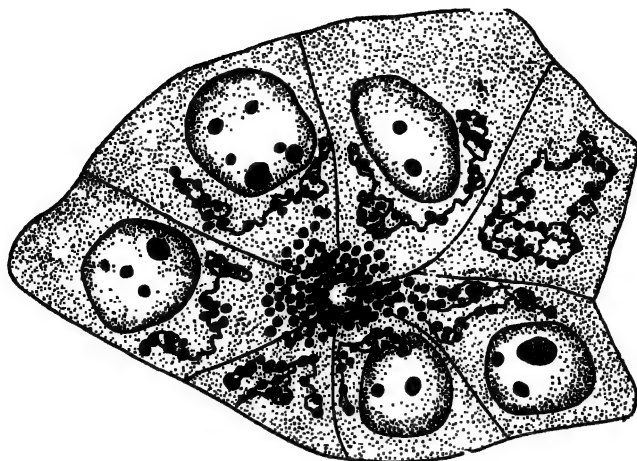


Fig. 2. Internal reticular apparatus (in cells of pancreas)

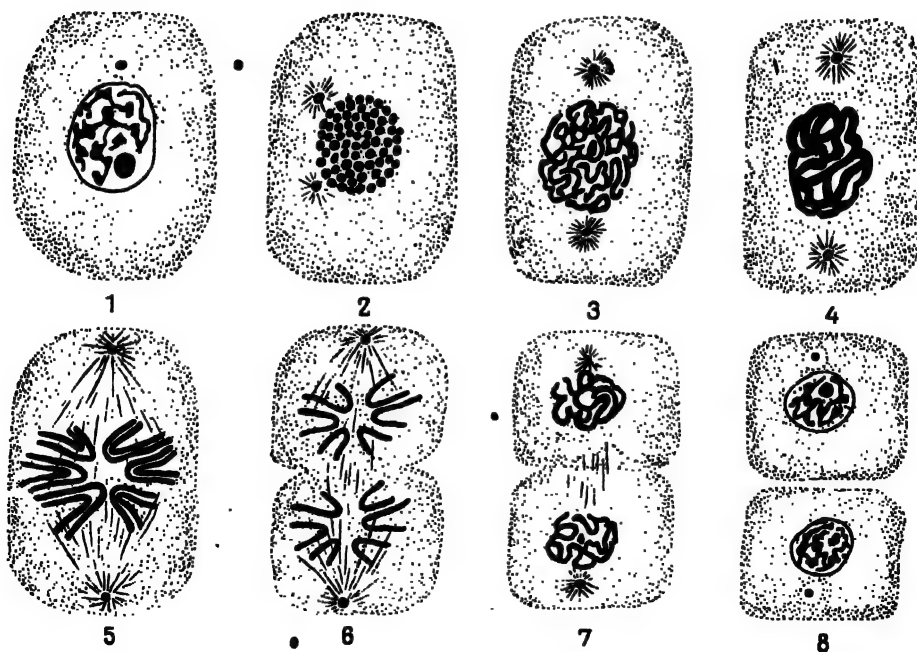


Fig. 3. Karyokinesis or indirect division of animal cells (schematic)

1—cell; 2—prophase, granular nucleus; 3—prophase, dense ball; 4—prophase, loose ball; 5—metaphase; 6—anaphase; 7—telophase; 8—two cells after division

**Karyokinesis**, or mitosis, or indirect division, is the most common method of cell division in the human organism. Four stages are distinguished: the prophase, metaphase, anaphase and telophase.

At the beginning of karyokinesis, during the *prophase*, the nuclear substance in the homogeneous nucleus (Fig. 3-2) concentrates into numerous minute granules. The granules gradually grow larger, coalesce and form a thin coiled chromatin filament (Fig. 3-3). At the same time the nuclear membrane disappears and the centrioles of the central body move apart to the poles of the cell. By the end of the prophase they have formed filaments of achromatin substance. As a result of the continuing concentration of nuclear substance (Fig. 3-4) the filament becomes much thicker and shorter. Since the nuclear membrane has disappeared it lies directly in the cytoplasm. Then the chromatin filament divides longitudinally and the two resultant filial filaments lie close to one another. After this the split chromatin filament breaks up into separate parts, called chromosomes, which arrange themselves in the cytoplasm in a disorderly manner. All these changes in the cell correspond to the first phase, or prophase, of karyokinesis.

During the next stage, the *metaphase* (Fig. 3-5), the chromosomes arrange themselves along the equator of the cell and the filaments of the achromatin spindle fasten themselves to individual chromosomes. The metaphase ends by each parent chromosome splitting into two daughter chromosomes.

During the *anaphase* (Fig. 3-6) the daughter chromosomes move apart to the poles of the cell. At the same time a constriction forms in the middle of the cell body and it gradually divides into two.

In the final stage, the *telophase* (Fig. 3-7), all the processes described above are reversed. The achromatin spindle disappears and a central body is formed from the centrioles. The nuclear substance concentrated in the chromosomes spreads out uniformly, a nucleolus and nuclear membrane appear, and the nucleus forms. The cell body divides completely and two separate young cells are produced (Fig. 3-8).

**Amitosis** or direct cell division was long considered an inadequate division characteristic of dying cells. But amitosis is observed in very many tissues, especially in those of embryos. Completely viable cells are formed as the result of amitosis. In amitosis the nucleus becomes elongated and a constriction appears. The nucleolus divides simultaneously. The region of the constriction thins out and the nucleus is cut in half, forming two daughter nuclei with nucleoli. In some cases the division of the nucleus is followed by division of the cell, but sometimes the cell body does not divide and binuclear or multinuclear cells are formed.

## TISSUES

The organs of the human body are made up of various tissues. Each tissue constitutes a single living system of cells and intercellular substance with a definite structure and definite function. The tissues acquired their structure and function in the process of evolution of the animal kingdom. The tissues of the organism fall into four groups: (1) epithelial tissue; (2) connective tissue, (3) muscular tissue, and (4) nervous tissue.

### *Epithelial Tissue*

Epithelial tissue forms the outer layer of the skin, lines the inner surface of the mucous and serous membranes, and makes up the glands.

The common feature of all epithelial tissue is that it is made up mainly of cells and has very little intercellular substance. Epithelial cells are of different shapes and, as a rule, form layers. The epithelium is separated from the underlying tissues by a very thin membrane, called the **basement membrane**.

There are three main types of epithelium named after the shapes of the cells: *columnar*, *cuboidal* and *squamous* (Fig. 4). In **simple epithelium** the cells are arranged in one layer, and in **stratified epithelium** they are arranged in several layers. The cells of stratified epithelium usually have their own characteristics (shape, size, etc.).

The following main types of epithelial tissue are distinguished according to their functional properties connected with their structural peculiarities.

**Tegumentary epithelium** forms the outer layer of the skin and some of the mucous membranes (the oral cavity, part of the pharynx, etc.). This epithelium is *stratified*. Its deepest layer is called **germinal epithelium**. It is formed of columnar cells which are used to replace the other cells of the epithelium. The next layer is made up of prickly cells which are interconnected by their prickles. The outer cells are flattened and the outer layers of the tegumentary epithelium consist of thin platelets which gradually *desquamate* (are cast off). These outer platelets (for example, in the epithelium of the skin) contain a dense horny substance.

The tegumentary epithelium has a protective function; it protects the organism against the action of various chemical, thermal and mechanical agents. At the same time it participates in metabolism: some waste products are excreted through it, heat is eliminated, etc.

**Ciliated epithelium** lines the mucous membrane of the respiratory tract. It is simple. On the surface facing the lumen of the respiratory tract its cells are equipped with vibratile cilia. They vibrate in an undulatory manner in the direction opposite to the stream of inhaled air and expel dust particles from the air which settle on the mucous

membrane. Thus the ciliated epithelium of the respiratory tract plays an essentially protective role. In human beings ciliated epithelium is also present in the uterine tubes where the vibrations of the cilia help to move the ovum.

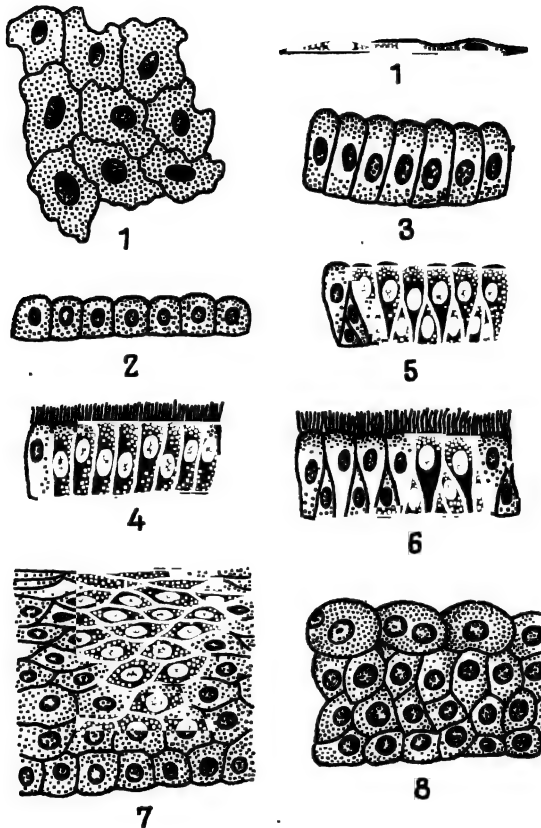


Fig. 4. Structure of epithelium (diagram)

1—simple squamous; 2—simple cuboidal; 3—simple columnar; 4—simple ciliated; 5—stratified columnar; 6—stratified ciliated; 7 and 8—stratified epithelium

**Intestinal epithelium** lines the mucous membrane of certain parts of the intestines. It is a simple columnar epithelium which has a special structure, or border, on its surface. Its principal function is to absorb nutrient substances produced in the digestion of food. Intestinal epithelium also plays a protective role by safeguarding the underlying tissues against the digestive action of the digestive juices.

**Glandular epithelium** is the main tissue of special organs called glands. The cells of glandular epithelium produce and discharge special substances. This function of the glands is called a secretory function and the substances they produce are known as **secretions**. In some cases the ability to produce secretions is peculiar to individual cells present in the epithelial layer; these are **unicellular glands**

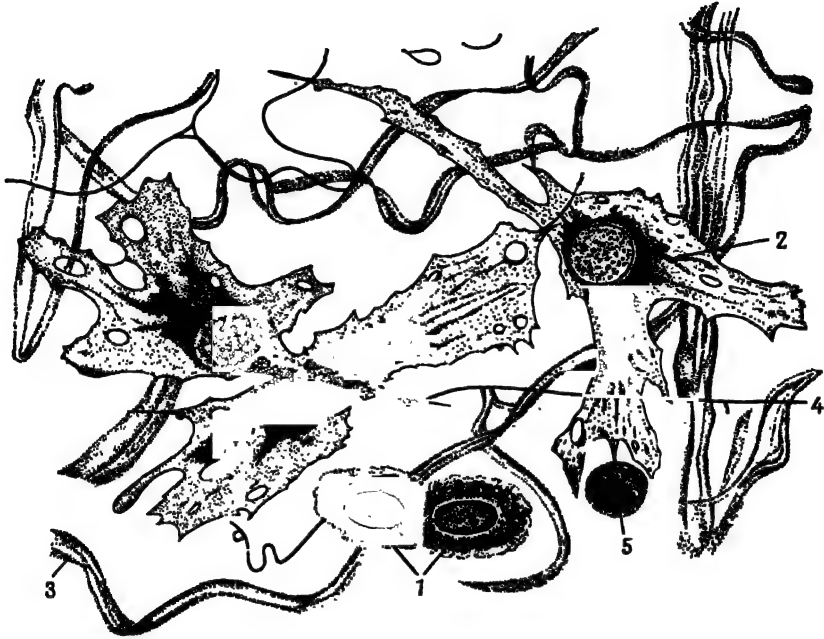


Fig. 5. Loose fibrous connective tissue

1—fixed macrophages; 2—fibroblast; 3—collagenous fibres; 4—elastic fibres; 5—lymphocyte

(for example, the goblet cells of the intestinal epithelium, which secrete mucus).

In other cases specific secretions are produced by complex organs, the **multicellular glands** (salivary glands, thyroid gland, etc.). Some glands have excretory ducts and are called **exocrine glands**; other glands have no excretory ducts, discharge their secretions directly into the blood and are known as **endocrine glands**.

The **epithelium of the urinary tubules** forms the main part of the renal substance and is a simple cuboidal or columnar epithelium with unclear boundaries between the cells. It performs an excretory function (participates in the formation of urine).



The **epithelium of serous membranes** (or the mesothelium) lines the membranes of internal cavities—the serous membranes (peritoneum, pleura and pericardium)—and is simple and flat. The mesothelium covers the layers of the serous membranes which face each other and prevents their adhesion. Moreover, it participates in the secretion of a serous fluid which is present as a thin layer between the surfaces of the serous membranes and thereby reduces friction during movement.

### Connective Tissue

Connective tissue is formed of cells and intercellular substance; unlike the intercellular substance of other tissues, that of connective tissue is as clearly marked as the cells.

This group of tissues includes the *trophic tissues* such as blood and lymph, *mixed tissues* which perform both trophic and supportive functions (loose fibrous connective tissue and its varieties), and *supportive tissues*, i.e., the dense fibrous connective tissue, cartilage and bone.

The structure of the blood and lymph will be described below (Chapter 8, "Blood. Cardiovascular System").

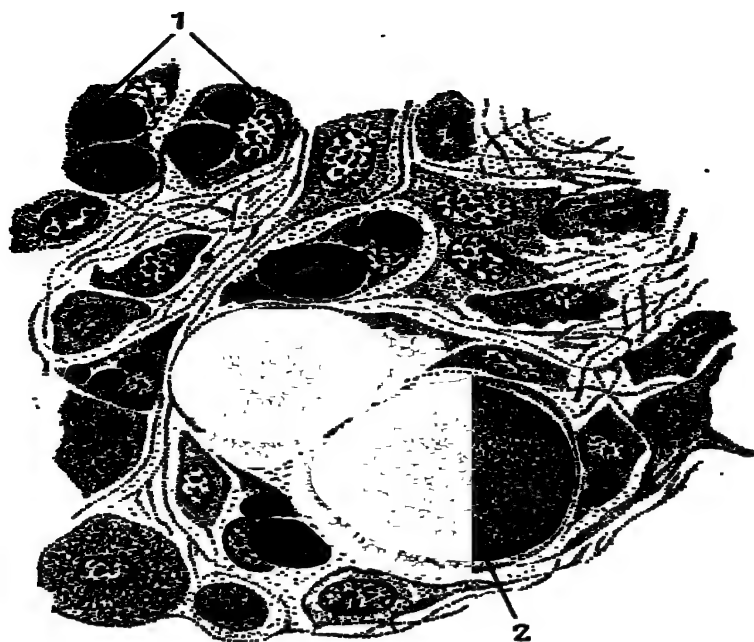
**Fibrous connective tissue.** Depending on the density of fibres in the intercellular substance, loose and dense fibrous connective tissues are differentiated.

**Loose fibrous connective tissue** (and its varieties) is found throughout the organism (Fig. 5). It accompanies blood vessels, forms layers between organs, the subcutaneous layer, etc. In short, it is a constituent of all organs without exception. The *cells of this tissue*, mainly fibroblasts and fixed macrophages, have different forms and functions. *Fibroblasts* are large, dendritic and usually elongated cells; they are connected with the formation of intercellular substance, and especially the fibres of loose fibrous connective tissue.

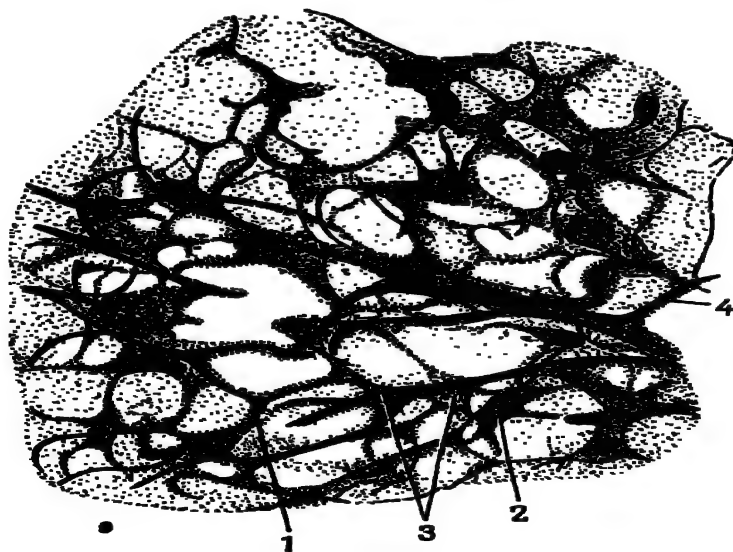
*Fixed macrophages*, or wandering cells at rest, are usually rounded or oval. They are capable of independent movement and **phagocytosis**, i.e., active ingestion of dense particles and their digestion (if they are of an organic nature). The Russian scientist I. Mechnikov was the first to describe the phenomenon of phagocytosis.

In addition to these main types of cells, loose connective tissue also contains *fat cells*, *reticular cells*, etc.

The *intercellular substance* of loose fibrous connective tissue is formed by the main, structureless, viscous substance and the various fibres lying in it. The *collagenous* (or gelatinous) fibres are thin and non-dendritic; they form bundles and are scarcely resilient. The *elastic* fibres are thin and dendritic, and do not form bundles; they stretch readily and when the stretching force ceases to act they quickly return to their former state.



**Fig. 6. Adipose tissue**  
 1—macrophages; 2—fat cells



**Fig. 7. Reticular tissue**  
 1 and 4—connective-tissue fibres; 2 and 3—cells

Loose fibrous connective tissue performs supportive, protective and trophic functions. The *supportive function* is performed by the fibres which form the stroma (framework) of the organ and lend it strength and elasticity. The *protective function* is performed by the macrophages, the cells which actively participate in the struggle to prevent microbes, the causative agents of disease, from entering the organism. The *trophic function* is performed by the ground substance of this tissue taking part in the nutrition of the tissues of various organs. The nutritive substances pass from the blood into the tissues of the organs through the walls of blood vessels which always accompany connective tissue. Thus, in order to reach the tissues of an organ the nutritive substances must pass through the walls of the blood vessels into the adjacent connective tissue. Which particular substances will pass into the organs, in what amounts and at what rate depends on the state of the vessel walls and of the ground substance of the connective tissue.

Adipose and reticular tissues are varieties of loose fibrous connective tissue.

**Adipose tissue** (Fig. 6) forms the subcutaneous cellular tissue, the layers surrounding vessels and many organs, and part of the omentum, etc. In addition to the cells and intercellular substance typical of loose fibrous connective tissue, adipose tissue contains a large number of fat cells. It has mainly a trophic function because it contains a reserve of fat which, when needed, is utilized by the organism. Adipose layers also perform a mechanical function as they protect some organs (for example, vessels) from injury.

**Reticular tissue** (Fig. 7) is the basic constituent of haematopoietic organs and forms part of some other organs. In this tissue the cells are connected by protoplasmic processes; such structures of a multinucleate mass of protoplasm are called *syncytium*. Macrophages, cells capable of phagocytosis, may detach themselves from the syncytium. Like loose connective tissue, reticular tissue performs trophic and protective functions; its supportive role is insignificant.

**Dense fibrous connective tissue** forms tendons (Fig. 8), ligaments, and the derma (true skin), and performs a supportive function. It is noted for its highly developed intercellular substance, particularly the bundles of collagenous fibres. The tissue also contains elastic fibres and a small amount of structureless substance. Between the fibres there are cells (fibrocytes, etc.).

**Cartilaginous tissue.** There are three types of cartilaginous tissue—hyaline, elastic and fibrous—distinguished by the structure of their intercellular substance. All cartilages perform a mechanical function.

**Hyaline cartilage** (Fig. 9) forms the cartilaginous parts of the ribs, the greater part of the laryngeal cartilages, and the articular cartilages of most of the joints. Under the microscope its intercellular sub-

stance looks like a homogeneous hyaline mass, but investigation by special methods reveals a structureless matrix and fibres which closely resemble collagenous fibres in their structure. The matrix contains cartilaginous cells in oval capsules.

**Elastic cartilage** forms the basis of the pinna of the ear and of the epiglottis. It differs from hyaline cartilage in that the matrix has a dense network of elastic fibres.

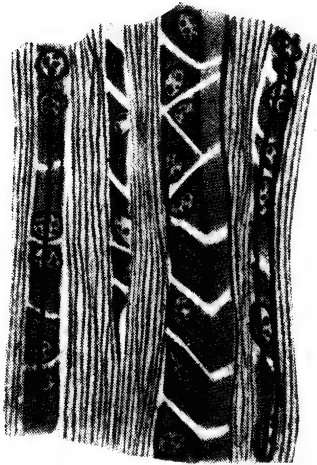


Fig. 8. Longitudinal section of tendon

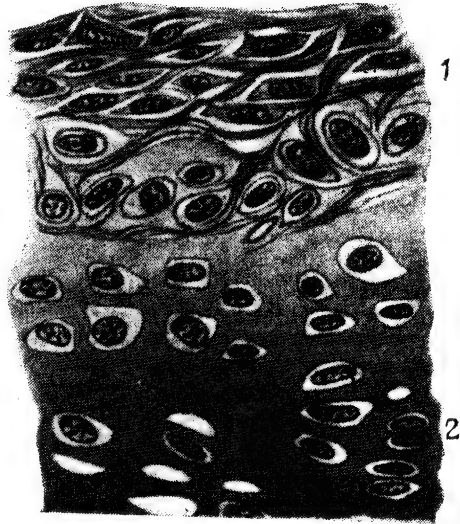
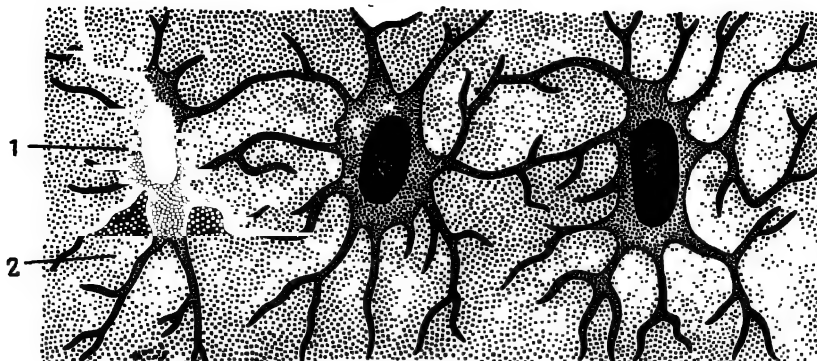


Fig. 9. Hyaline cartilage  
1—perichondrium; 2—cartilaginous tissue

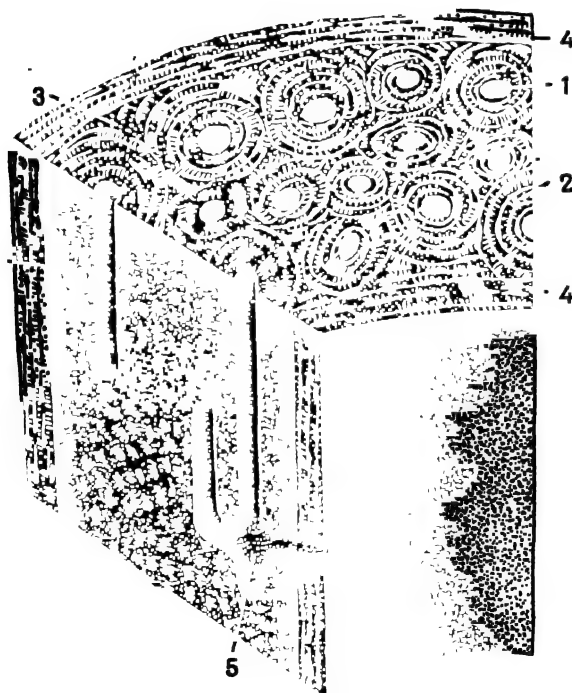
**Fibrocartilage** is found in some articulations of bones (for example, in the intervertebral disks) and where tendons are attached to bones. The intercellular substance of this cartilage contains many parallel and clearly marked bundles of collagenous fibres and very little matrix.

All types of cartilage are covered with *perichondrium* which is a type of loose fibrous connective tissue. Cartilage is nourished by the perichondrium and grows from it.

**Bony tissue** is formed by bone cells, called *osteocytes*, and intercellular substance (Fig. 10). Osteocytes are dendritic cells whose processes are connected with each other. The cell bodies occupy special bone cavities, and their processes are situated in the so-called *bone canaliculi*. The intercellular substance consists of a structureless matrix and fibres which resemble collagenous fibres in compo-



**Fig. 10. Bony tissue**  
 1—bone cells, or osteocytes; 2—intercellular substance



**Fig. 11. Structure of bone**  
 1—Haversian canal; 2—Haversian systems; 3—interstitial bone plates; 4—common bone plates; 5—Volkmann's canal; 6—longitudinal section of Haversian canal

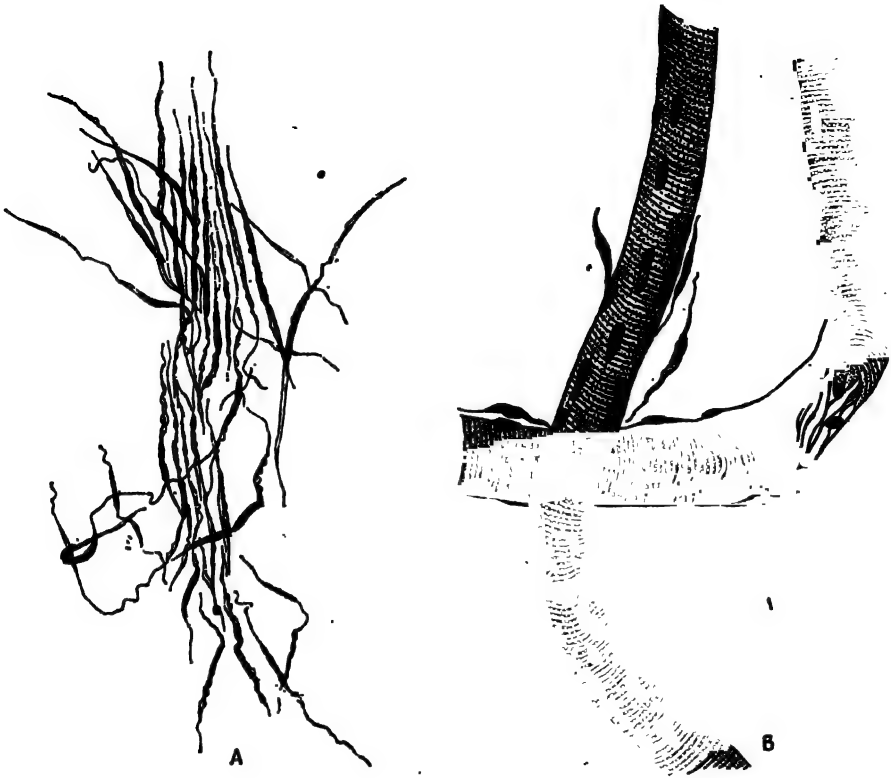


Fig. 12. Muscular tissues  
A—smooth muscle fibres; B—striated muscle fibres

sition and properties. Unlike other types of connective tissue, however, the intercellular substance of bony tissue contains mineral salts (calcium phosphate, calcium fluoride, etc.) which give it special strength.

The main structural unit of bone is the *osteon* (Fig. 11), a system of concentrically arranged plates of bone. These plates take the form of cylinders arranged one inside the other and are called Haversian systems. In the centre of the osteon is a canal called the Haversian canal. The Haversian canals contain blood vessels giving off from larger vessels which enter the bone along so-called Volkmann's canals. There are interstitial bone plates between the osteons.

There are also external and internal common bone plates.

### *Muscular Tissue*

This group includes tissues differing in structure and origin: smooth muscular tissue and striated muscular tissue. The common characteristic of these tissues is their contractility.

**Smooth muscular tissue** is a constituent of the walls of internal organs (intestine, bladder, uterus, etc.) and blood vessels, and is found in the skin. Its structural element is the muscle fibre, a spindle-shaped cell (Fig. 12A) which is 60-100  $\mu$  long and consists of sarcoplasm (i.e., cytoplasm) with a rod-shaped nucleus. The sarcoplasm contains special structures—contractile filaments or myofibrils.

**Striated (striped) muscular tissue** forms the skeletal muscles, the muscle of the heart and some internal organs (pharynx, tongue, soft palate, etc.). Its structural element is the muscle fibre which in man reaches a length of 12.5 cm. In addition to sarcoplasm, the muscle fibre (Fig. 12B) contains a large number of nuclei and has a membrane. The sarcoplasm contains longitudinal filaments, myofibrils, which are not uniform, but consist of alternating dark and light stripes (hence the name of the muscle fibre—striated, or striped).

Muscle fibres form bundles separated from each other by layers of thin, loose fibrous connective tissue.

### *Nervous Tissue*

**Nervous tissue** is the main component of the nervous system which regulates all the processes of the organism and determines the relationship between the organism and its surrounding environment.

The main properties of nervous tissue are excitability and conductivity. The nervous system responds to the various stimuli which act on the organism by excitation. The excitation is transmitted (conducted) by the nervous tissue in the form of so-called nerve impulses. Nervous tissue is made up of nerve cells and neuroglia.

The **nerve cell**, or **neuron** (Fig. 13), consists of the cell body, its processes and endings. Neurons are described, according to the number of processes, as unipolar (with one process), bipolar (with two processes), or multipolar (with three or more processes). There are also pseudounipolar cells; one process gives off from the body of such a cell and then divides into two processes. The nerve cells are described, according to their function, as sensory, internuncial, motor, etc. Each neuron has one (or more, depending on the type of neuron) process, the dendrite, along which excitation is transmitted to the cell body, and one process, the neurite or axon, along which excitation is conducted away from the cell body. Dendrites are usually short and branched, while neurites are long. Only certain nerve cells have long dendrites.

The body of the neuron contains a nucleus and cytoplasm (neuroplasm). Besides the organelles (reticular apparatus, etc.) common to all cells, the cytoplasm of the neuron contains special structures connected with the specific function of nervous tissue. These are the **neurofibrils** (very fine fibrils) which run through the cell body without interruption from one process to another. Another special structure of neuroplasm is the so-called **tigroid substance** (Nissl substance); special methods of examination reveal that this substance is made up of grains and small lumps. The tigroid substance disappears from a cell which has been innervating an organ working for a long time; it reappears when the cell is in a state of rest.

**Nerve fibres**, the processes of nerve cells, are composed of cytoplasm with neurofibrils running through. The membranes of the processes are not uniform in structure, and myelinated and unmyelinated nerve fibres are distinguished. Myelinated nerve fibres have a sheath of a white fatty substance called **myelin**; unmyelinated fibres have no such sheath. The nerve endings (Fig. 14) either receive stimulation or transmit excitation to working organs. The former are called **sensory endings or receptors**, and the latter are called **motor (in muscles) and secretory (in glands) endings**.

Nerve impulses pass from one cell to another across a synapse which is the region of communication between two neurons.

The second element of the nervous system is the **neuroglia** (Fig. 15) which consists of cells of various shapes, but mainly dendritic (stellate and dendriform). Neuroglia cells are not only present in the brain and spinal cord but also, in the so-called sheaths of Schwann, accompany the nerve fibres arising from the brain.

In nervous tissue the neuroglia performs trophic, protective and partly supportive functions.

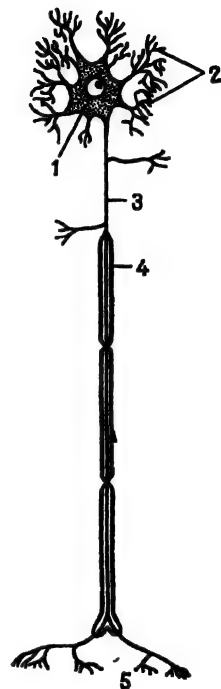


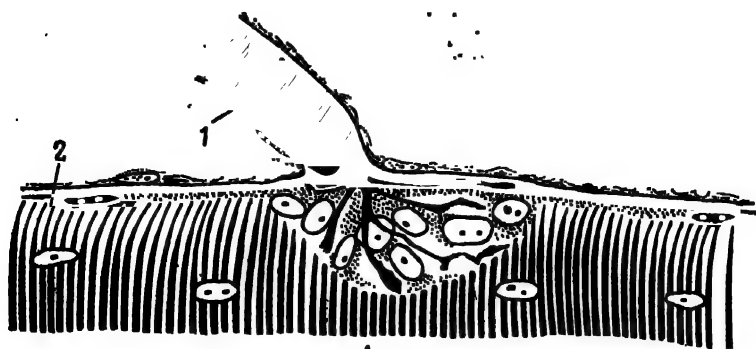
Fig. 13. Diagram of a neuron

1—cell body with nucleus; 2—dendrites; 3—neurite; 4—myelin sheath; 5—terminal ramifications

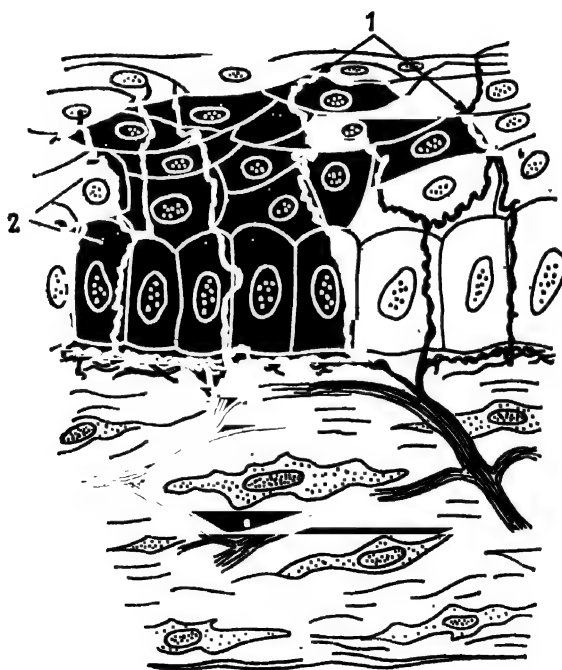
### CONCEPT OF ORGAN AND SYSTEM OF ORGANS

In the human body there are numerous organs: bones, muscles, stomach, heart, brain, spinal cord, etc. Each organ has a complex structure and carries out a definite function. An organ is composed





A



B

**Fig. 14. Nerve endings**

**A**—motor ending on muscle fibre; **1**—nerve fibre; **2**—muscle fibre; **B**—free nerve endings in epithelium; **1**—free nerve endings; **2**—epithelial cells

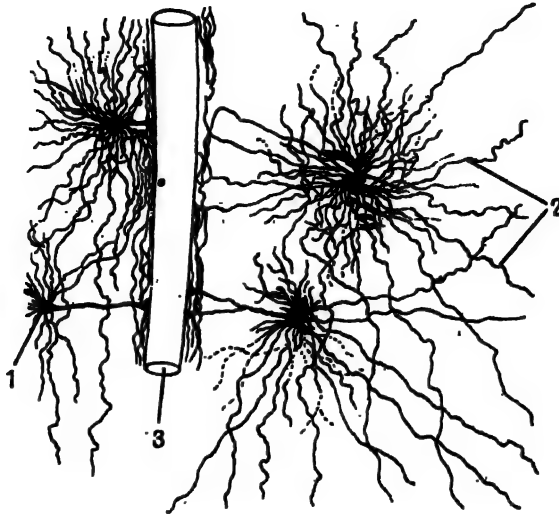


Fig. 15. Neuroglia cells

1—cell body; 2—processes; 3—blood capillary

of various tissues, but the greater part of the organ is made up of tissue associated with the specific function of the given organ. For example, a muscle contains muscular tissue, loose connective tissue and certain other tissues, but the bulk of the muscle is composed of muscular tissue which determines the contractile property of the muscle.

Each organ has blood vessels, and most organs also have lymphatic vessels; all organs are supplied with nerves which branch inside them.

Organs with similar functions are united to form systems of organs. Such systems are the bony system, muscular system, digestive system, respiratory system, urogenital system, endocrine system, cardiovascular system, nervous system and the system of the sense organs.

The digestive, respiratory and urogenital organs are usually called internal organs or viscera. Most of these organs are in the thoracic, abdominal and pelvic cavities.

Not infrequently the term *parenchymatous organs* is used in the clinic and in pathologic anatomy. This term is used to designate the internal organs which are composed of main tissue called parenchyma and enclosed in connective tissue called stroma. The parenchyma is usually formed of epithelial cells with different structures and functions. The liver, lungs and kidneys are examples of parenchymatous organs and differ from the hollow internal organs which have the form of a tube or sac (stomach, intestines, bladder, etc.). The

walls of hollow organs are composed of several coatings or membranes made of various tissues.

The main functions of the various systems of organs are given briefly below.

The bones and joints form the skeleton which supports the whole body. The muscles and skeleton together form the supportive-motor apparatus.

The respiratory system performs the function of gaseous interchange between the organism and its external environment; the organism receives oxygen and expels carbon dioxide.

Through the digestive system the organism receives nourishment. In the organs of the digestive system proteins, fats, carbohydrates and other substances contained in food undergo complex changes and are transformed into simpler, water-soluble substances which can then be absorbed.

The cardiovascular system contains the blood which continuously circulates throughout the organism owing to the contractions of the heart. The main function of the blood is to deliver nutrients and oxygen to all organs and simultaneously to carry metabolites (products of metabolism) away from them.

The urinary organs excrete waste products. The lungs (which eliminate carbon dioxide) and the skin also participate in the elimination of waste products. The skin in addition has a protective function; it safeguards the organism against harmful agencies in the external environment.

The genitalia are concerned in the function of reproduction.

The endocrine glands secrete special substances called *hormones* which enter the blood and are transported throughout the organism; hormones influence different functions, particularly metabolism.

Through the sense organs (receptors) the nervous system perceives various stimuli in the external environment and internal organs, which underlies our sensations.

The nervous system regulates the activities of all organs and the connections between them and; consequently, ensures the integrity of the organism. The relationship between the organism and its external environment is established predominantly through the nervous system (and the sense organs connected with it).

The nervous system includes the brain, spinal cord and nerves. The brain and spinal cord make up the central nervous system, and the nerves form the peripheral nervous system. The cerebral cortex is the highest part of the nervous system. The nerves are divided into *sensory* or *afferent*, and *motor* or *efferent* nerves. Impulses are transmitted from the receptors along the sensory nerves to the spinal cord and brain; impulses travel along the motor nerves from the central nervous system to the organs.

## THE ORGANISM AS A WHOLE

**Integrity of the organism.** The organism is a single system. In a complex organism cells and intercellular substance form tissues, tissues make up organs, and organs unite in systems. All the cells, tissues, organs and systems of organs are closely interconnected and affect each other.

The vital activities of the cells, tissues, organs and the whole organism are based on metabolism which consists of two interconnected processes—assimilation of nutritive substances (anabolism) and decomposition of organic substances (catabolism). The complex substances of the cells and tissues continuously split into simpler ones; at the same time they are renewed from other substances delivered to the cells and tissues from outside. The catabolism in the cells and tissues is accompanied by liberation of energy which operates all the processes in the organs and tissues (muscular contraction, heart action, cerebral activity, etc.), including anabolism.

During the vital activities of the organism, which are based on metabolism, the various organs and systems of organs establish close connections and interactions. This may be readily demonstrated on a skeletal muscle. Metabolism takes place in the muscle, as in other organs. This naturally requires a continuous supply of nutrients and oxygen which are delivered by the blood through the blood vessels. The nutrients enter the blood from the digestive system, and the oxygen from the respiratory system (through the lungs). The waste products formed in the process of metabolism pass from the muscles into the blood and are transported to the excretory organs and eliminated. The blood flows through the blood vessels because of the contractions of the heart whose work, like that of the other organs, is regulated by the nervous system.

The relations between the various systems of organs can also be demonstrated by the co-ordinated changes in their activities. Intensification of the activity of one organ or system of organs is accompanied by changes in the other systems. For example, physical work causes metabolism to increase sharply in the muscles. This leads to a co-ordinated change in the activity of the cardiovascular, respiratory, excretory and other systems.

The interdependence between the various organs and the entire organism also manifests itself in disease. Pathologic changes in one particular organ affect other systems of organs. The principle of integrity of the organism implies that the disease of any organ must not be regarded as a purely local disturbance, but as a morbid state of the entire organism.

**Organism and environment.** The organism and the external conditions required for it to live constitute a unity. The different exter-

nal factors such as temperature and humidity of the air, composition and amount of food, etc., affect the organism. The human organism is also influenced by conditions of work and rest, housing and other social conditions. Many external factors are harmful to man (for example, pathogenic microbes) and under certain conditions may serve as the causes of his diseases.

Unlike animals, man can deliberately improve his surroundings. The planting of greenery in populated areas, artificial irrigation of these areas and other measures can change the climatic conditions. Control of disease carriers (flies, mosquitoes, etc.), proper rest and diet, physical exercise and other measures help to prevent disease.

**Concept of regulation of the organism's functions:** The organism is continuously acted upon by certain stimuli. To all these stimuli the organism responds in a definite way. For example, a bright light causes constriction of the pupils; a drop in temperature is accompanied not only by a constriction of the blood vessels of the skin, but also by an increase in tissue metabolism and, consequently, increased heat production; stimulation of the taste receptors by food in the oral cavity evokes salivation, etc. The various stimuli are perceived by receptors. The resultant excitation is transmitted along sensory nerves to the central nervous system and from there along motor nerves to the organs which respond with a definite reaction. Such responses of the organism to stimuli, effected through the central nervous system, are called **reflexes**. The path which the excitation follows during a reflex reaction is known as the **reflex arc**. Reflexes vary in character; I. Pavlov divided them into unconditioned and conditioned reflexes. Unconditioned reflexes are inborn and are transmitted through heredity. The sucking reflex, pupillary reflex, salivary reflex in response to stimulation of the taste buds with food, etc. are examples of unconditioned reflexes.

Conditioned reflexes are acquired in the course of the animal's or man's lifetime. They arise only under certain conditions and may disappear. Salivation at the sight and smell of food, and in man even at the mention of food, is an example of a conditioned reflex.

In a living organism the regulation of all functions is of a reflex character and operates on the principle of self-regulation. Many functions are regulated automatically, independent of our consciousness; for example, the blood pressure is maintained at a definite level, the salts in the blood are maintained in a constant composition, metabolism is altered in a strictly co-ordinated manner, and the activity of the heart, the respiratory and other systems increases during physical work.

It should be remembered that all systems of organs are interconnected not only through the nervous system, but also humorally (humor—fluid), i.e., through the blood and other fluids circulating in

the body. Various chemical substances (hormones, metabolites, etc.) enter the blood and are carried throughout the organism. These substances have particular effects on the activities of the different organs and on the organism as a whole.

The relationship between the organisms and its external environment is effected not only directly through the nervous system but also chemically, through the food consumed by man and through the air he breathes. Thus a unified neurohumoral regulation of functions is characteristic of the organism of man (and of all highly developed animals).

## ANATOMICAL TERMINOLOGY

Various terms are used in anatomy to describe the positions of parts and organs. The human body is conventionally viewed in a vertical position with arms hanging at the sides, palms supinated. Mutually perpendicular planes and axes are conventionally drawn through the body: *sagittal*, *frontal* and *horizontal* planes, and *sagittal*, *transverse* and *vertical* axes. The sagittal plane runs anteroposteriorly, the frontal runs parallel to the surface of the forehead, and the horizontal runs parallel to the line of the horizon. The sagittal plane drawn through the middle of the body and dividing it into two equal halves (right and left) is called the *median* plane.

The most commonly used anatomical terms describing the position of parts relative to the planes and axes are:

*Superior* (upper) or *cranial* (*cranium*, skull)—closer to the upper part of the body.

*Inferior* (lower) or *caudal* (*cauda*, tail)—closer to the lower part of the body.

*Proximal*—closer to the trunk or median line of the body—and *distal*—farther away from the trunk or median line of the body; these terms are used when referring to the extremities.

*Anterior* or *ventral* (*venter*, belly or abdomen)—situated at the front or closer to the front surface of the body.

*Posterior* or *dorsal* (*dorsum*, back)—situated at the back or closer to the back surface of the body.

*Medial*—situated closer to the median line of the body—and *lateral*—situated farther away from the median line of the body.

In anatomy all organs and their parts have Latin names. The Latin anatomical terminology has been adopted by the International Congress of Anatomists and is used in most countries.

This textbook makes use of only the most essential Latin terms.

## *Bones and Articulations (Skeleton)*

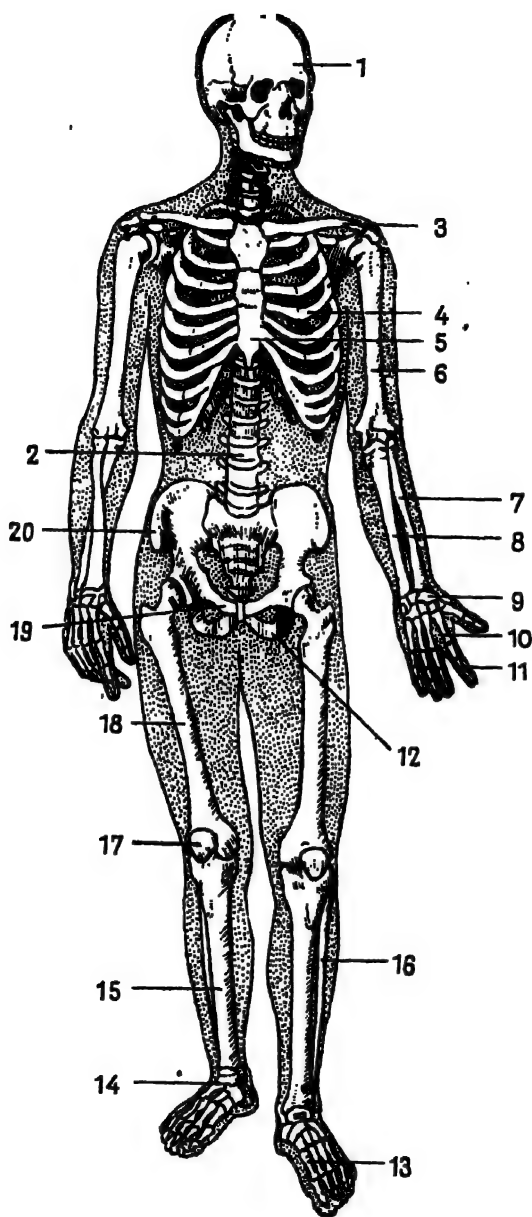
The bones and their articulations form the skeleton of the human body (Fig. 16).

The skeleton performs functions of support, movement and protection. The supportive function consists in supporting all the other organs and giving the body a definite form and position in space. The skeleton, together with the muscles, constitutes the motor apparatus. In this apparatus the bones play a passive role; they are levers shifting as the result of muscular contractions. The protective function of the skeleton consists in safeguarding the other organs against mechanical influences. For example, the skull protects the brain, the thorax (chest) protects the heart and lungs, and the pelvis protects the bladder, rectum and other organs.

### STRUCTURE OF BONES

A bone (in Latin *os*) is structurally a complex organ. The greater part of a bone consists of bony (osseous) tissue (see Chapter 1, "Cells and Tissues") which is formed of compact and spongy bony substance. The bone marrow found inside bones is an inalienable part of bones. The surfaces of bones are investigated in periosteum. Each bone, like all other organs, is supplied with nerves, blood and lymphatic vessels.

The bone marrow (*medulla ossium*) lies inside the bones between the bone plates of the spongy substance and in the bone canals of some bones. There are red and yellow types of bone marrow. The yellow bone marrow consists predominantly of fat while the red bone marrow is a **haematopoietic** (blood-forming) organ; it produces blood cells.



**Fig. 16. Human skeleton (anterior aspect)**

*1—skull; 2—vertebral column; 3—clavicle; 4—rib; 5—sternum; 6—humerus; 7—radius; 8—ulna; 9—carpal bones; 10—metacarpal bones; 11—phalanges of the fingers; 12—ischium; 13—metatarsal bones; 14—tarsal bones; 15—tibia; 16—fibula; 17—patella; 18—femur; 19—pubic bone; 20—ilium*



The **periosteum** is a fibrous membrane which invests the surfaces of bone (Fig. 17). It has two layers; the external layer consists of dense connective tissue and performs a protective function, while the internal layer consists of loose connective tissue and contains many nerve fibres and blood vessels. From the periosteum the nerve fibres and blood vessels penetrate deep into the bone through special orifices. The internal layer of the periosteum contains cells, called *osteoblasts*, which participate in the formation of bony tissue during the growth of the bone and in the healing of fractured bones. A bone dies if it loses the periosteum.

The articular surfaces of bones are covered not with a periosteum, but with articular cartilage which in most bones is made of hyaline cartilaginous tissue.

**Chemical composition.** The composition of bones includes organic substances (ossein and osseomucoid) and inorganic compounds (chiefly various calcium salts). The resilience of bone depends on the presence of organic substances, while the hardness of bone depends on the presence of inorganic compounds. If a bone is tempered, its organic substances burn while the mineral salts remain; as a result the bone will retain its shape, but will become very brittle. A bone immersed in a solution of hydrochloric or nitric acid retains its organic substances, but its inorganic compounds dissolve (i.e., decalcification of the bone takes place). In such a case the bone will retain its shape, but will lose its hardness, i.e., it will bend easily. Organic substances constitute about one-third and inorganic substances about two-thirds of the weight of a bone. The organic substances (in per cent) decrease with age and the mineral salts increase, so that the bones of elderly people are less resilient than those of children.

**Shape of bones.** Bones are called long, short, flat and mixed, according to their shapes. Long bones are found in the limbs (the upper arm bone, forearm bones, thigh bone and shin bones). Each of these bones has a middle part, called the shaft or diaphysis, and two ends, or epiphyses\*. The diaphyses of bones consist of compact bony substance.

\* The terminal part of the diaphysis where it joins the epiphysis is called the metaphysis.

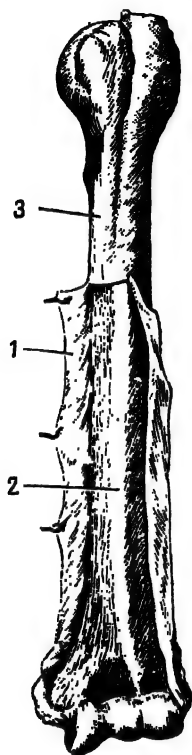


Fig. 17. Periosteum. Left humerus

1—periosteum; 2—portion of bone stripped of periosteum; 3—portion of bone covered with periosteum

There is a bone canal inside the diaphysis, and for this reason such bones are called tubular. The bone canal is filled with bone marrow. The epiphyses of tubular bones consist mainly of spongy bony substance, but their outer surface is covered with a thin layer of compact substance. The bone plates of the spongy substance form bony trabeculae arranged in a definite pattern. The arrangement of the bony trabeculae varies from bone to bone and depends on the pressure exerted on the given bone in the human body and the traction to which it is subjected by the contraction of the muscles attached to it (Fig. 18).

Short bones have various structures. Some of them, such as the bones of the metacarpus, metatarsus and phalanges, are analogous in structure to long tubular bones. Other short bones, such as the vertebrae and bones of the carpus and tarsus, are like the epiphyses of the long bones and consist predominantly of spongy substance whose outer surface is covered with a thin plate of compact substance.

Flat bones (bones of the skullcap, breastbone, ribs, etc.) consist of two plates of compact substance with a layer of spongy substance in between (Fig. 19). Mixed bones (bones of the base of the skull) consist of several parts which differ in structure.

**Development of the skeleton.** Most human bones go through three stages of development: membranous, cartilaginous and osseous. The skeleton develops from the mesenchyme, the foetal tissue from which most of the connective tissues develop. During its early stages the skeleton of human foetus is represented by the chorda dorsalis (in some lower animals the chorda remains as the skeleton for life). However, by the middle of the first month of intrauterine life a condensation of mesenchyme appears round the chorda; this condensation will later become the vertebral column which replaces the chorda. At about the same time condensations of mesenchyme also appear in other places, forming the primary skeleton of the foetus. This skeleton is formed from an indurated mesenchyme and is called a membranous skeleton. At about the middle of the second month (the periods for the different parts of the skeleton differ) the mesenchyme

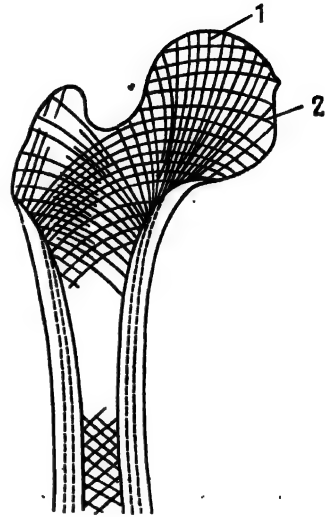


Fig. 18. Diagram showing arrangement of trabeculae in spongy substance. Section of upper end of the femur

1—trajectories of compression;  
2—trajectories of tension

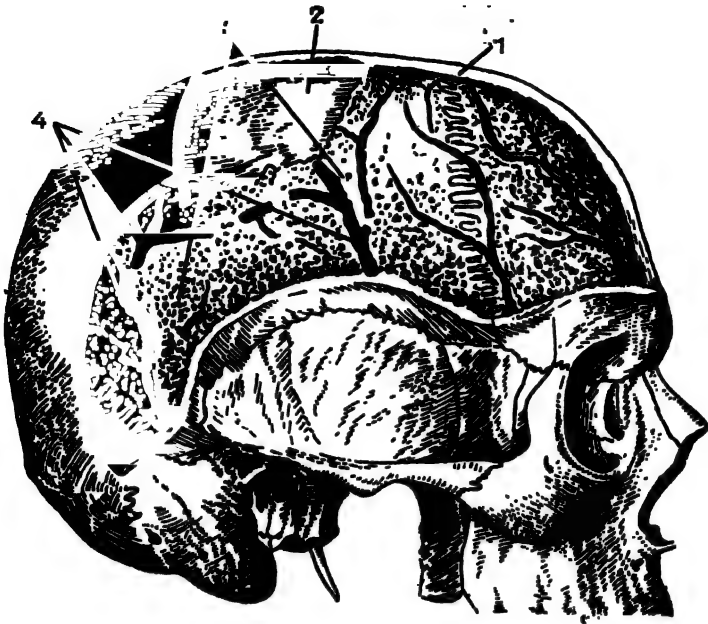


Fig. 19. Structure of flat bones of the skull

1—external plate of compact bony substance; 2—internal plate; 3—spongy substance (diploë); 4—veins in spongy substance

forming the membrane bones is transformed into a hyaline cartilage; this is the second stage in the development of the skeleton which is now called a cartilaginous skeleton. At the end of the second or the beginning of the third month the cartilaginous skeleton begins to ossify. This process operates in such a manner that the cartilage disintegrates and is replaced by bony tissue. One or more areas of bony tissue appear in each bone; these areas are called points of ossification. The points of ossification gradually enlarge and replace the cartilage. In the long bones cartilaginous layers between the diaphysis and epiphysis persist for a long time. They are called epiphyseal cartilages. The cells of epiphyseal cartilages for some time retain their ability to multiply, and as a result the bone grows in length. Complete replacement of epiphyseal cartilages by bony tissue occurs at different periods and ends only when a person is 20-25 years old. After that bones no longer grow in length. Bones also grow in thickness by new layers of bony substance being deposited from the periosteum; this growth also ceases when a person is 20-25 years old. The bones

of the skullcap, and most of the bones of the facial skull do not go through the cartilaginous stage and are formed directly by ossification of the mesenchyme forming the membrane bones.

### BONE ARTICULATIONS

All bones of the human body are articulated. There are three main types of bone articulation: syndesmoses, synchondroses and joints (Fig. 20).

**Syndesmoses** are bone articulations by means of fibrous connective

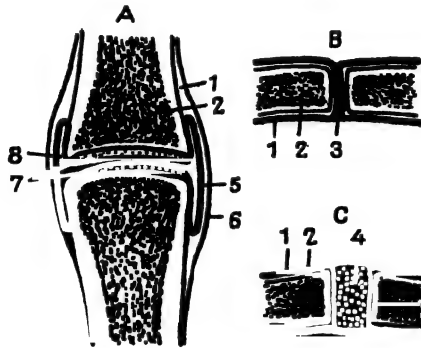


Fig. 20. Types of bone articulations (diagram)

A—joint; B—syndesmosis; C—synchondrosis; 1—periosteum; 2—bone; 3—fibrous connective tissue; 4—cartilage; 5—synovial layer of joint capsule; 6—fibrous layer of joint capsule; 7—articular cartilages; 8—articular cavity

tissue. They include ligaments (for example, between the spinous processes of the vertebrae), and membranes (for example, the interosseous membrane between the two forearm bones). Sutures, the union of the skull bones by means of thin layers of fibrous connective tissue, are a type of syndesmosis. These sutures usually ossify in elderly people.

**Synchondroses** are bone articulations by means of cartilaginous tissue. An example of synchondrosis is the articulation of the bodies of vertebrae by means of intervertebral cartilages. During the development of the skeleton the cartilages between some bones are replaced by bony tissue with the result that the bones form a union by means of osseous material—synostosis. The union of the sacral vertebrae is an example of synostosis.

Syndesmoses and synchondroses form a group of continuous articulations, i.e., articulations which have no cavity. Movement in syndesmoses and synchondroses is very slight or completely absent.

### SKELETON OF THE TRUNK

The skeleton of the trunk consists of the spine and the thorax.

#### Spine

The spine or vertebral column (*columna vertebralis*) (Fig. 22) supports the trunk and consists of 33 or 34 vertebrae and their arti-

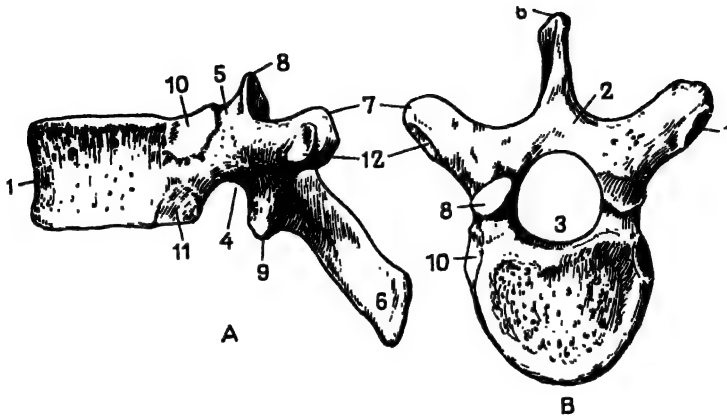


Fig. 23. Thoracic vertebra

A—lateral aspect; B—superior aspect; 1—body of vertebra; 2—arch of vertebra; 3—vertebral foramen; 4—inferior notch; 5—superior notch; 6—spinous process; 7—transverse process; 8—superior articular process; 9—inferior articular process; 10 and 11—articular fossae on body of vertebra; 12—articular fossa on transverse process

culations. The spine is made up of five sections: *cervical*, consisting of 7 vertebrae, *thoracic*—12 vertebrae, *lumbar*—5 vertebrae, *sacral*—5 vertebrae, and *coccygeal*—4 or 5 vertebrae. In adults the sacral and coccygeal vertebrae are fused and form the sacrum and coccyx.

A vertebra consists of a body and an arch; the arch supports seven processes: one spinous, two transverse and four articular (two superior and two inferior) (Fig. 23). The body serves as the anterior surface of the vertebra, and the spinous process is directed backwards. The space included between the body and the arch is called the vertebral foramen. The vertebral foramina of all the vertebrae together form the vertebral canal which contains the spinal cord. The vertebral arches have indentations—superior and inferior notches. The notches of adjacent vertebrae form the intervertebral foramina through which the spinal nerves pass.

The vertebrae of the different sections of the vertebral column differ in structure.

The *cervical vertebrae* (Fig. 24) have foramina in their transverse processes giving passage to the vertebral artery. The ends of the spinous processes are bifurcated.

The first cervical vertebra, the atlas (Fig. 24), has no body, but has anterior and posterior arches which are interconnected by lateral masses. It articulates with the occipital bone by means of its superior articular surfaces which have the form of fossae, and it articulates with the second cervical vertebra by means of the inferior articular surfaces.

The second cervical vertebra, the axis (Fig. 24), has an odontoid process (dens) which articulates with the anterior arch of the atlas. The spinous process of the seventh cervical vertebra is not bifurcated; it juts out to the rear and is easily palpated.

The *thoracic vertebrae* (see Fig. 23) have articular fossae on the bodies for articulation with the heads of the ribs, and on the transverse processes for articulation with the tubercles of the ribs. The thoracic vertebrae have the longest spinous processes which are directed backwards and downwards.

The *lumbar vertebrae* are the largest and have spinous processes pointing directly backwards.

The *sacrum* (Fig. 25) consists of 5 fused vertebrae. It may be divided into a superior broad part, the base, an inferior narrow part, the apex, and two lateral parts. The anterior, or pelvic, surface of the sacrum is concave; it has 4 pairs of anterior sacral foramina. The posterior surface is convex and has ridges, or crests, resulting from the fusion of the vertebral processes, and 4 pairs of posterior sacral foramina. The sacral foramina give passage to nerves. Inside the sacrum there is the sacral canal which is a continuation of the vertebral canal. At the point where the sacrum and the fifth lumbar vertebra articulate, anteriorly, there is a prominence, called the promontory. There are articular surfaces of auricular form on the lateral parts of the sacrum for articulation with the pelvic bones.

The *coccyx* consists of 4 or 5 underdeveloped fused vertebrae and is a vestige of the tail of man's ancestors.

**Articulations of the spine.** The vertebrae are articulated by means of cartilages, joints and ligaments. The bodies of the vertebrae are joined by means of cartilages. These cartilages are called intervertebral disks. Anterior and posterior longitudinal ligaments extend along the vertebral column on the anterior and posterior surfaces of the bodies of the vertebrae. The joints of the vertebrae are formed by articular processes, and are called intervertebral; because of the shape of the articular surfaces they are regarded as gliding joints. There are also ligaments between the arches of the vertebrae (*ligamenta flava*), the transverse processes (intertransverse ligaments) and the spinous processes (interspinal ligaments). The apices of the spi-

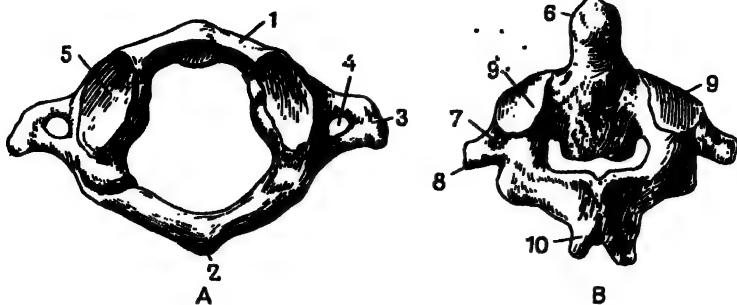


Fig. 24. First and second cervical vertebrae

*A*—first cervical vertebra (superior aspect); 1—anterior arch; 2—posterior arch; 3—transverse process; 4—foramen in transverse process; 5—superior articular fossa; *B*—second cervical vertebra (posterior aspect); 6—dens; 7—foramen in transverse process; 8—transverse process; 9—articular surfaces for articulation with atlas; 10—spinous process

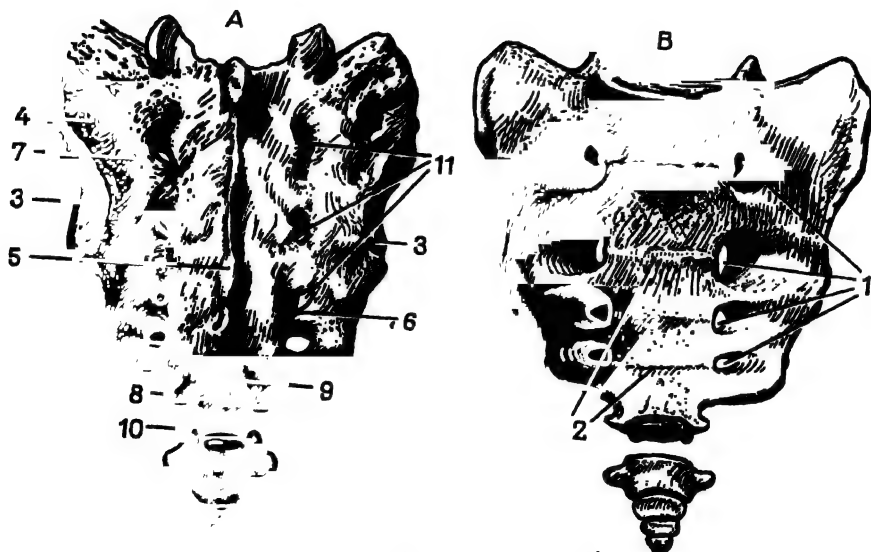


Fig. 25. Sacrum and coccyx

*A*—posterior aspect; *B*—anterior aspect; 1—anterior sacral foramina; 2—anterior (or pelvic) surface; 3—auricular surface; 4—lateral part; 5, 6 and 7—crests on posterior surface of sacrum; 8—apex of sacrum; 9—inferior foramen of sacral canal; 10—coccyx; 11—posterior sacral foramina

nous processes are articulated by a supraspinal ligament which in the cervical section of the spine is called the nuchal ligament.

The anterior and posterior atlanto-occipital membranes stretch between the arches of the atlas and the occipital bone. The superior articular fossae of the first cervical vertebra together with the occipital bone form a paired condyloid atlanto-occipital joint. This joint allows slight flexion, extension and lateral bending. There are 3 joints between the first and second cervical vertebrae which make it possible for the atlas (together with the head) to rotate about the odontoid process, or dens, of the second cervical vertebra.

The spine allows flexion, extension, lateral bending and torsion. Its most mobile sections are the lumbar section and then the cervical section.

**Spinal curvatures.** The spine of a newborn child is almost straight. As the child develops, spinal curves form. The spine of an adult has two forward curves, the cervical and lumbar curves, and two backward curves, the thoracic and sacral curves. They are a normal phenomenon associated with man's upright posture and are of mechanical importance since they diminish the jarring of the head and trunk during walking, running and jumping. An exaggeration of the forward curve is known as *lordosis*, and the exaggeration of the backward curve is known as *kyphosis*. Some people develop a lateral curvature of the spine, which is called *scoliosis*. Pronounced scoliosis is a result of pathologic conditions in the spinal column.

### *Thorax*

The thorax consists of the breastbone, 12 pairs of ribs, the thoracic vertebrae and their articulations (Fig. 26).

The **breastbone**, or **sternum** is a flat bone in the central anterior part of the thorax (Fig. 26). The sternum is made up of three parts: the superior part, or manubrium, the middle part, or body, and the inferior part, or xiphoid process. The manubrium articulates with the body at an obtuse angle projecting forwards.

On the superior border of the sternum there is the so-called jugular notch of the sternum; on its lateral borders there are notches for the clavicles and 7 pairs of ribs.

The sternum sometimes has to be punctured to extract red bone marrow from the spongy substance of the bone for microscopic examination.

The **ribs** (*costae*) are long, flat curved bones (see Fig. 26). Each rib consists of a bony part and cartilage. It has a body, two ends—anterior and posterior, two borders—superior and inferior, and two surfaces—external and internal. The posterior end of the rib has a head, neck and tubercle. At the inferior border of the internal surface of



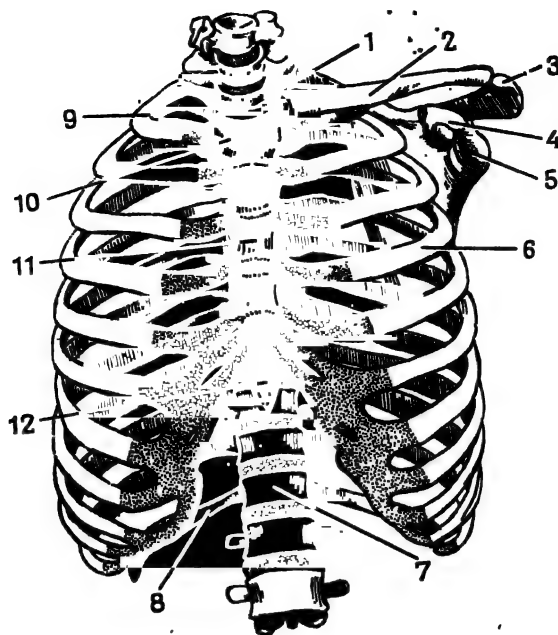


Fig. 26. Skeleton of thorax

1—first thoracic vertebra; 2—clavicle; 3—acromial process of scapula; 4—coracoid process of scapula; 5—glenoid cavity of scapula; 6—ribs (4th); 7—12th thoracic vertebra; 8—12th rib; 9—1st rib; 10—manubrium; 11—body of sternum; 12—xiphoid process of sternum

the rib there is a groove for lodgement of nerves and blood vessels. Man has 12 pairs of ribs. The first pair differs from the others in that it is almost horizontal. On the upper surface of each of the first ribs there is the scalene tubercle (for the insertion of the scalenus anterior muscle) and two grooves for the subclavian artery and the subclavian vein. The last two pairs of ribs are the shortest. In the human body the ribs lie obliquely—the anterior ends are lower than the posterior ends.

**Articulations of the thorax.** The posterior ends of the ribs form joints with the thoracic vertebrae, the heads of the ribs articulating with the bodies of the vertebrae and the tubercles with their transverse processes. These joints allow the ribs to be raised and lowered. The anterior ends of the top seven pairs of ribs (first-seventh pairs) articulate by means of their cartilages with the sternum. These ribs are conventionally called **true ribs**. The remaining 5 pairs of ribs (eighth-twelfth pairs) do not articulate with the sternum and are called **false ribs**. The cartilages of the eighth, ninth and tenth ribs are

each attached to the cartilage of the overlying rib, forming the costal arch. The eleventh and twelfth pairs of ribs end freely at the front in muscles; they are the most mobile ribs and are called the **floating ribs**.

### THE THORAX AS A WHOLE

The thorax contains the following important internal organs: heart, lungs, trachea, oesophagus, large blood vessels and nerves. As a result of the rhythmic movements of the thorax its capacity increases and decreases, and inhalations and exhalations take place.

The size and shape of the thorax depend on age, sex and individual differences. It is shaped like a truncated cone; it is longer from side to side than from back to front. The upper opening of the thorax is bounded by the first pair of ribs, the first thoracic vertebra and the jugular notch of the sternum. The lower opening is wider than the upper one and is bounded by the twelfth thoracic vertebra, the eleventh and twelfth pairs of ribs, the costal arches and the xiphoid process of the sternum.

The thorax of a newly born child is shaped like a pyramid; it is longer from back to front than from side to side and its ribs lie almost horizontal. The shape of the child's thorax changes as the child grows. The female thorax is smaller than that of the male. The upper part of the female thorax is relatively broader than that of the male thorax. Disease may alter the shape of the thorax. For example, in cases of severe rickets the thorax takes the shape of what is known as a chicken, or pigeon, breast (the sternum is very prominent). Systematic physical exercise from childhood (under medical observation) encourages correct development of the thorax, and of the entire organism.

### SHOULDER GIRDLE AND UPPER EXTREMITIES

The shoulder girdle is formed by two pairs of bones: the collarbones (clavicles) and the shoulder blades (scapulae). The bones of the arms include those of the upper arms, forearms and hands. The bones of the hands include those of the carpus, metacarpus and the phalanges of the fingers.

#### *Bones and Articulations of the Shoulder Girdle*

The **clavicle** is a curved bone resembling the italic "f" in shape (Fig. 26); it consists of a body and two ends called the sternal and acromial ends.

The **scapula** is a flat triangular bone (Fig. 27). It has an anterior, or costal, surface and a posterior surface, coracoid and acromial processes and an articular depression called the glenoid cavity. The

anterior surface faces the ribs and has a depression called the subscapular fossa. The bony prominence on the posterior surface of the scapula, called the spine of the scapula, divides the posterior surface of the bone into two depressions called the supraspinous and infraspinous fossae. The glenoid cavity of the scapula articulates with the bone of the upper arm.

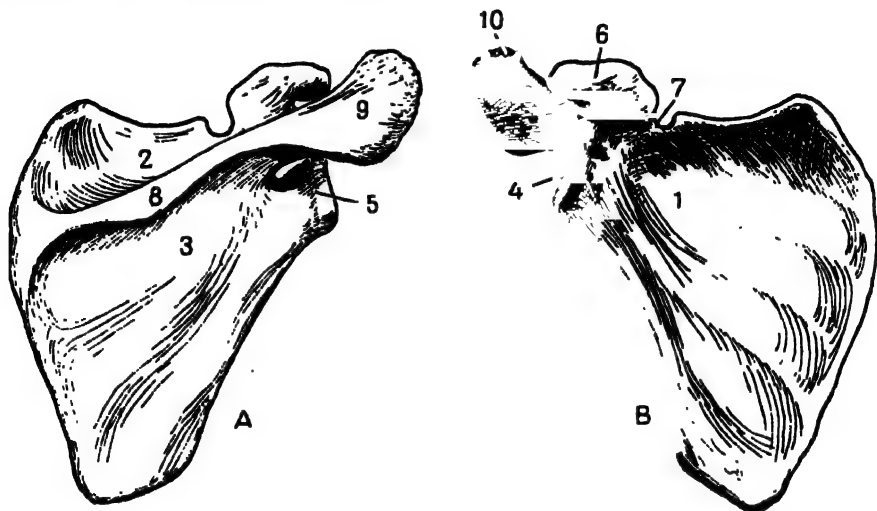


Fig. 27. Scapula (right)

*A*—posterior aspect; *B*—anterior aspect; 1—subscapular fossa; 2—supraspinous fossa; 3—Infraspinous fossa; 4—glenoid cavity; 5—neck of scapula; 6—coracoid process; 7—notch; 8—spine; 9 and 10—acromial process

**Articulations of the bones of the shoulder girdle.** The ends of the clavicle articulate with the manubrium and the acromion, forming two joints, the sternoclavicular and acromioclavicular joints. The sternoclavicular joint may be saddle-shaped (saddle joint) or spheroid (ball-and-socket joint); it has an intra-articular cartilage, or disk. The joint allows upward, downward, forward and backward movements of the clavicle. The acromioclavicular joint is a gliding joint and allows only slight movement of the bones. Both joints are bound by ligaments. A dense ligament known as the coracoacromial ligament stretches between the acromial and coracoid processes.

### *Bones and Articulations of the Arm*

The humerus (upper arm bone) is a long tubular bone. It consists of a shaft or diaphysis, and two ends, or epiphyses (Fig. 28). At the upper end of the humerus is the head which articulates with the sca-

pula, the greater and lesser tubercles, and the constricted portion called the anatomic neck. Below the tubercles the humerus narrows down somewhat to form the surgical neck (fractures of the humerus usually occur at this site). The shaft of the bone has openings for

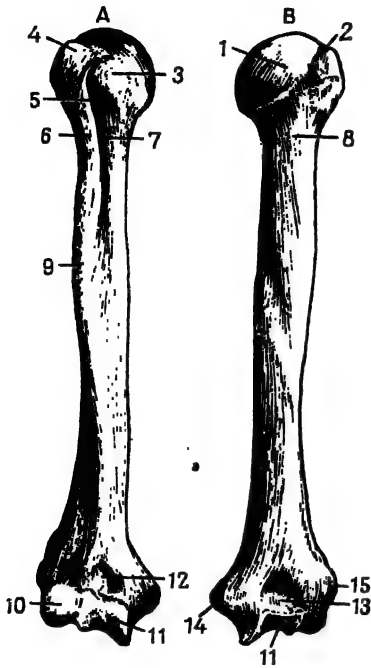


Fig. 28. Humerus (right)

*A*—anterior aspect; *B*—posterior aspect; 1—head; 2—anatomical neck; 3—lesser tubercle; 4—greater tubercle; 5—bicipital groove (or intertubercular sulcus); 6—crest of greater tubercle; 7—crest of lesser tubercle; 8—surgical neck; 9—deltoid tuberosity; 10 and 11—articular surface for articulation with forearm bones; 12—coronoid fossa; 13—olecranon fossa; 14—medial epicondyle; 15—lateral epicondyle

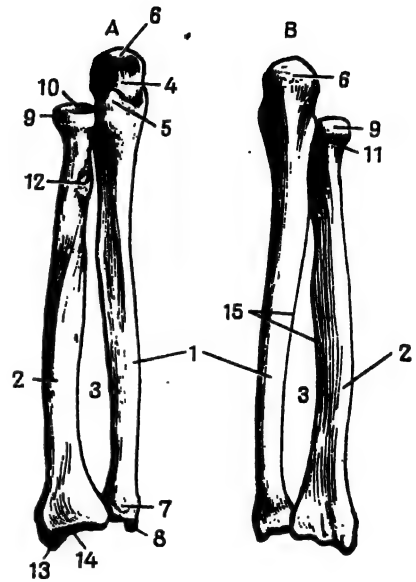
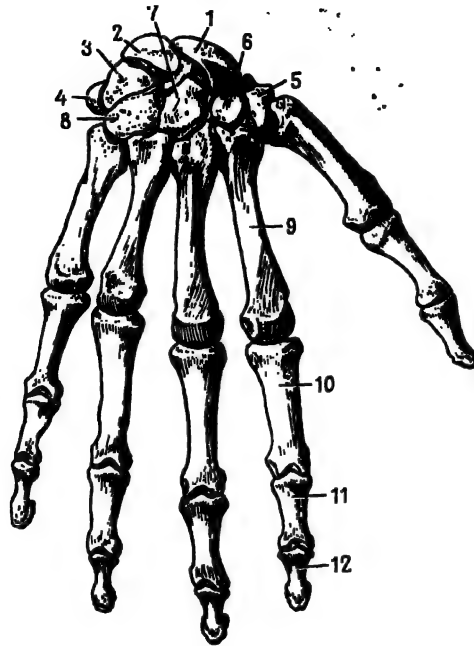


Fig. 29. Bones of the forearm (right)

*A*—anterior aspect; *B*—posterior aspect; 1—ulna; 2—radius; 3—interosseous space; 4—semilunar notch; 5—coronoid process; 6—olecranon; 7—head of ulna; 8—styloid process of ulna; 9—head of radius; 10—fossa on head of radius; 11—neck of radius; 12—tuberosity of radius; 13—styloid process of radius; 14—articular surface of radius for articulation with carpal bones; 15—interosseous crests

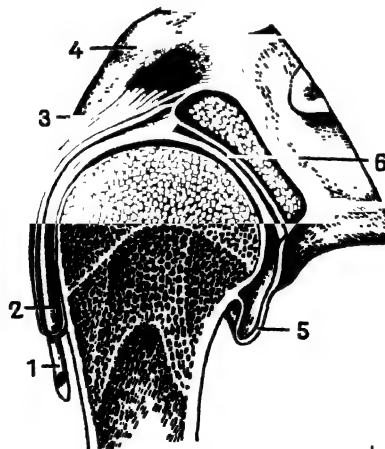
blood vessels (nutrient openings) and nerves, and part of it has a rough surface for the attachment of the deltoid muscle.

On the sides of the lower end of the bone there are rough eminences called the medial and lateral epicondyles. This end also has articular surfaces for articulation with the ulna and radius, and two fossae called the coronoid and olecranon fossae.



**Fig. 30. Bones of right hand, dorsal aspect**

1—navicular; 2—lunate; 3—triquetral; 4—pisiform; 5—greater multangular; 6—lesser multangular; 7—capitate; 8—hamate; 9—metacarpal (2nd); 10—proximal phalanx; 11—middle phalanx; 12—ungual phalanx



**Fig. 31. Right shoulder joint (section)**

1—tendon of long head of biceps brachii; 2—synovial sheath of this tendon; 3 and 5—joint capsule; 4—acromial process of scapula; 6—glenoid cavity of scapula

**Bones of the forearm.** There are two forearm bones, the ulna and the radius. They are long tubular bones.

The ulna is the medial bone (Fig. 29). At its upper end are the coronoid and olecranon processes, the semilunar notch and a tuberosity; at its lower end are the head and the styloid process.

At the upper end of the radius are a head with a notch, a neck and a tuberosity; at the lower end it has an articular surface for articulation with the bones of the carpus, and a styloid process (Fig. 29). The diaphyses of both bones of the forearm are three-edged; their sharpest edges face each other and are called interosseous crests.

The bones of the hand (*manus*) are divided into those of the *carpus*, *metacarpus*, and the *phalanges of the fingers* (Fig. 30). There are eight carpal bones and they are arranged in two rows of 4 bones. The proximal row consists of the navicular, lunate, triquetral and pisiform bones. The distal row includes two multangular bones, greater and lesser, and the capitate and hamate (unciform) bones. Looking at the palm the carpal bones form the carpal sulcus over which a transverse ligament is stretched. Between the ligament and the carpal bones there is a space, the carpal canal, through which pass the tendons of the muscles. The metacarpus is formed of 5 bones which are numbered first, second, etc., from the thumb. They are tubular bones. Each metacarpal bone has a base, a shaft and a head. The bones of the fingers, the phalanges, are relatively small tubular bones. The thumb has two phalanges; the proximal and the ungual. Each of the other fingers has 3 phalanges; the proximal or first, the middle or second, and the ungual or third.

**Articulations of the bones of the arm.** The bones of the arm articulate by means of joints. The largest joints are the shoulder joint (*articulatio humeri*), the elbow joint (*articulatio cubiti*) and the radiocarpal joint (*articulatio radiocarpea*).

The shoulder joint (*articulatio humeri*) is formed by the glenoid cavity of the scapula and the head of the humerus (Fig. 31). This ball-and-socket joint allows flexion, extension, abduction, adduction, rotation and circumduction. The tendon of the long head of the *musculus biceps brachii* passes through this joint.

The elbow joint is made up of three bones: the humerus, the ulna and the radius (Fig. 32). The common joint capsule unites three articulations—*humero-ulnar*, *humero-radial* and *radio-ulnar*. The joint capsule is bound by ligaments. The elbow joint allows flexion and extension.

The forearm bones are articulated by an interosseous membrane and two radio-ulnar joints called the proximal and distal joints. The proximal joint forms part of the elbow joint. The radio-ulnar joints are

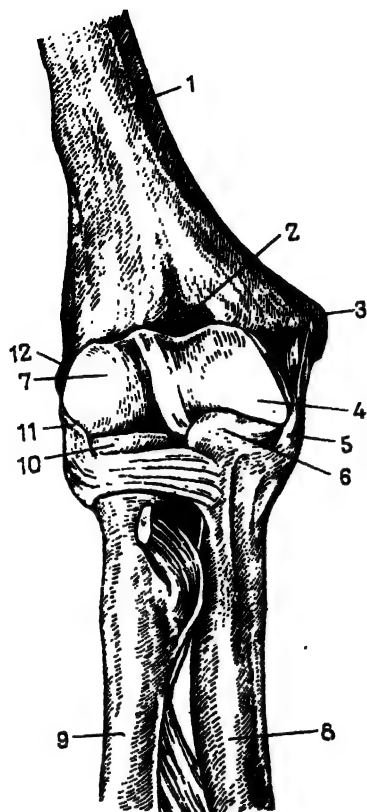


Fig. 32. Right elbow joint (anterior aspect)

1—humerus; 2—coronoid fossa of humerus; 3—medial epicondyle; 4 and 7—articular surfaces of humerus for articulation with forearm bones; 5 and 11—joint capsule and reinforcing ligaments; 6—coronoid process of ulna; 8—ulna; 9—radius; 10—head of radius; 12—lateral epicondyle of humerus

pivot joints and allow rotation about the longitudinal axis, the hand moving with the radius. Turning the forearm inward (palms down) is called pronation, and turning it outward is called supination.

The radiocarpal joint articulates the radius with the bones of the proximal row of the carpus and is a condyloid joint. It allows flexion, extension, abduction, adduction and circumduction. The joint capsule is reinforced by ligaments. The radiocarpal and intercarpal joints (the joint between the two rows of carpal bones) are together called the wrist joint.

The hand contains the following joints; (1) intercarpal (gliding); (2) carpometacarpal (also gliding except for the articulation between the greater multangular and first metacarpal bones, which is a saddle joint); (3) metacarpophalangeal (ball-socket); (4) interphalangeal (hinge). All the joints of the hand are binded by ligaments.

The joints of the arm, especially those of the fingers, allow a wide variety of movements. This is due to the fact that in the process of evolution the anterior extremity of man's ancestors developed into an organ of labour.

### PELVIC GIRDLE AND LOWER EXTREMITIES

The pelvic girdle or pelvis contains two large hip bones (coxae), one on each side.

The hip bones articulate with the sacrum and coccyx and together form the pelvis. The bones of the leg are the thigh bone, the bones of the shank and the bones of the foot. The bones of the foot are divided into the bones of the tarsus and metatarsus, and the phalanges of the toes.

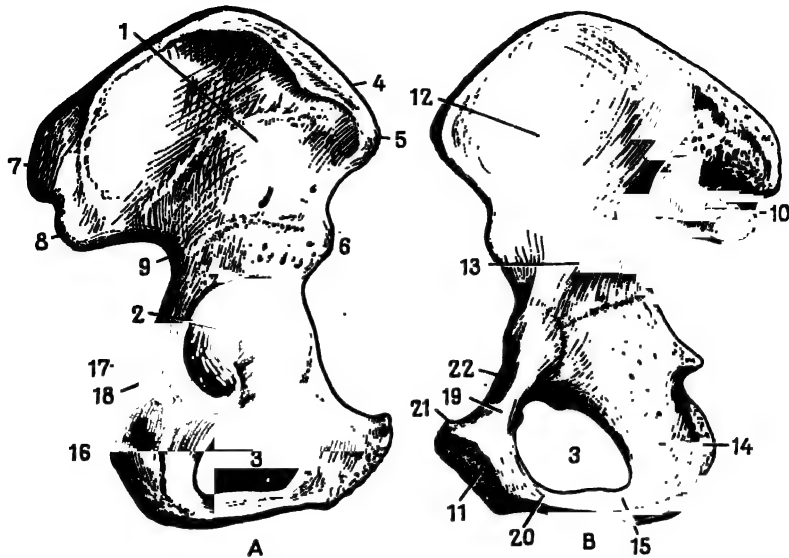


Fig. 33. Hip bone (right)

A—outer surface; B—inner surface; 1—ilium; 2—acetabulum; 3—obturator foramen; 4—iliac crest; 5—anterior superior spine; 6—anterior inferior spine; 7—posterior superior spine; 8—posterior inferior spine; 9—greater sciatic notch; 10—auricular surface; 11—surface for articulation with other half of pubic bone; 12—iliac fossa; 13—arcuate line of ilium; 14—superior branch and 15—inferior branch of ischium; 16—ischial tuberosity; 17—ischial spine; 18—lesser sciatic notch; 19—superior and 20—inferior branch of pubis; 21—pubic tubercle; 22—pubic pecten

### *Bones and Articulations of the Pelvis*

The hip bone (os innominatum or os coxae) is a union of 3 bones; the ilium, pubis and ischium.

At the site of their union is the acetabulum (Fig. 33), for articulation with the head of the thigh bone. The ilium has a body and a wing. The border of the wing is called the crest of the ilium, and ends in two prominences—the anterior superior and posterior superior spines. Below these prominences are the anterior inferior and posterior inferior spines. Also found on the ilium are the arcuate line, the iliac fossa, gluteal lines and an auricular articular surface.

The pubis consists of a body and two branches (rami), the superior ramus and the inferior ramus. On the superior ramus there are a pubic tubercle and a pubic crest (pubic pecten). The ischium consists of a body, superior and inferior rami, ischial tuberosity and the ischial spine. The ischial spine separates the greater sciatic notch from the lesser sciatic notch. The pubic and ischial rami bound the obturator foramen which is almost completely covered with connective tissue membrane.



**Articulations of the pelvis.** The pelvis has the following articulations: (1) sacroiliac joint (paired) formed by the auricular surface of the sacrum and the ilium; it is bound by strong ligaments and is a gliding joint; (2) pubic union or symphysis pubis, formed by the two pubic bones which articulate by means of a cartilage in which there is a slitlike cavity (such articulation is called hemiarthrosis); (3) proper ligaments of the pelvis: the sacrospinous ligament (between the sacrum and the ischial spine) and the sacrotuberous ligament (between the sacrum and ischial tuberosity). These ligaments together with the sciatic notches bound the greater and lesser sciatic foramina which carry muscles, nerves and blood vessels.

### *The Pelvis as a Whole*

The pelvis is formed by the two hip bones, sacrum and coccyx and their articulations (Fig. 34). The *greater* (or false) pelvis and the *lesser* (or true) pelvis are distinguished. The two pelvises are separated by the iliopectineal line which runs through the promontory, along the arcuate lines, through the pubic crests and the superior margin of the symphysis. The false pelvis is bounded by the iliac wings. The true pelvis is formed by the pubis, ischium, sacrum and coccyx. The entrance of the true pelvis is known as the inlet or superior strait and the exit is called the outlet or inferior strait.

The cavity of the true pelvis contains the bladder, rectum and internal genitalia (the female pelvis contains the uterus, uterine tubes and ovaries; the male pelvis contains the prostate, seminal vesicles and deferent ducts). The true pelvis of the female is the birth canal through which the child passes during parturition. The shape and size of the pelvis differ with sex. The female pelvis is broader, but lower than the male pelvis; the wings of the female ilia are more expanded, the promontory does not project so much into the pelvic cavity, and the sacrum is broader and less curved. The angle under the symphysis between the inferior pubic rami is less than a right angle in males, while in women it is obtuse and often has the shape of an arch. It is very important for obstetrical purposes to know the measurements of the female pelvis since they are subject to individual differences. Below are given the most important average measurements of the female pelvis.

1. The distance between the anterior superior iliac spines is called the spinous distance (*distantia spinarum*) and is 25-26 centimetres.
2. The distance between the farthest points of the iliac crests is called the crestal distance (*distantia cristarum*) and is 28-29 centimetres.
3. The distance between the greater trochanters of the thigh bones.

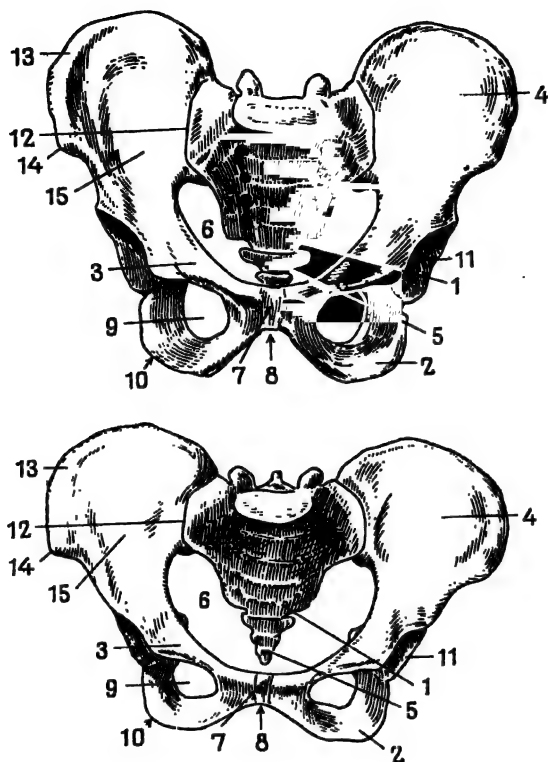
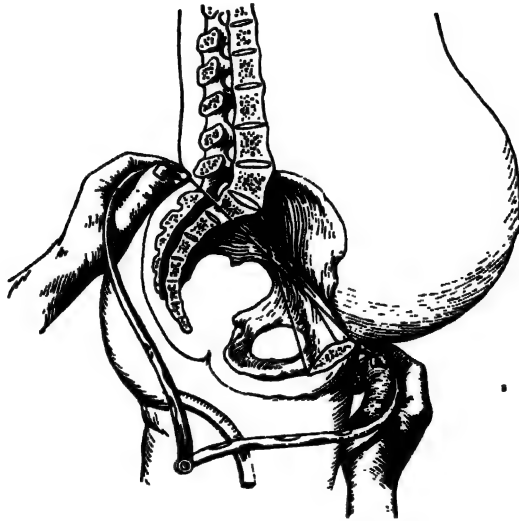


Fig. 34. Male (top) and female (bottom) pelvis

1—sacrum; 2—ischium; 3—pubis; 4—ilium; 5—coccyx; 6—inlet of true pelvis; 7—pubic symphysis; 8—angle under symphysis (pubic angle); 9—obturator foramen; 10—ischial tuberosity; 11—acetabulum; 12—sacroiliac joint; 13—iliac crest; 14—anterior superior spine; 15—iliac fossa

is known as the trochanteric distance (*distantiā trochanterica*)—and is 30-31 centimetres.

4. The distance between the superior margin of the pubic symphysis and the fossa, corresponding to the distance between the fifth lumbar vertebra and the sacrum, is called the external conjugate (Fig. 35) and is 20-21 centimetres. All the above measurements are taken outside the pelvis by means of a special instrument called a pelvimeter.



**Fig. 35. Measuring external conjugate (diagram)**

5. The distance between the inferior margin of the pubic symphysis and the promontory is called the diagonal conjugate—and is 12.5-13 centimetres. The diagonal conjugate is measured during a vaginal examination.

6. The distance between the promontory and the furthest back point on the internal surface of the pubic symphysis is called the obstetric or true conjugate and is 10.5-11 centimetres. The obstetric conjugate is determined from the external conjugate by subtracting 9 cm or more accurately from the diagonal conjugate by subtracting 1.5-2 centimetres.

7. The distance between the inferior margin of the pubic symphysis and the apex of the coccyx is measured to determine the size of the outlet of the true pelvis. This distance averages 11 centimetres. Subtraction of 1.5 centimetres (thickness of the coccyx and integuments) gives the size of the outlet of the true pelvis, which is about 9.5 cen-

timetres. During parturition this size may increase to 11 centimetres owing to the mobility of the coccyx.

The measurements of the male pelvis are 1.5 or 2 centimetres smaller than those of the female pelvis.

### *Bones and Articulations of the Leg*

The thigh bone (femur) is the longest tubular bone in the skeleton (Fig. 36). At its upper end it has a head, neck and two eminences called the greater and lesser trochanters. The shaft is shaped cylindrically and has a rough ridge, the *linea aspera*, on its posterior surface. At the lower end of the femur there are two eminences, the medial and lateral condyles, with the intercondylar fossa in between. There are eminences called the medial and lateral epicondyles on the sides of the condyles.

The kneecap (patella) is a triangular bone with rounded angles (see Fig. 16); it is situated at the lower end of the femur. The patella is developed in the tendon of the quadriceps femoris muscle; bones developed in the tendons of muscles are called sesamoid bones.

**Bones of the shank.** There are two bones in the shank—shin bone and the splint bone. They are both tubular bones.

The shin bone (tibia) is much thicker than the splint bone (fibula) and is the medial bone of the shank (Fig. 37). At its upper end it has medial and lateral condyles, an intercondylar eminence, two articular surfaces for articulation with the femur, and a tuberosity for the attachment of muscles. The shaft of the tibia is three-edged; its anterior margin is called a crest. At the lower end of the tibia there is an eminence, called the malleolus, and an articular surface for articulation with the talus.

The splint bone (fibula) has a head with an articular surface for articulation with the tibia at its upper end, and a malleolus with an articular surface for articulation with the talus at its lower end (Fig. 37).

The bones of the foot (the Latin term for foot is *pes*) are divided into those of the *tarsus*, *metatarsus* and *phalanges* of the toes (Fig. 38). There are 7 tarsal bones: the calcaneus, talus (or astragalus), navicular, cuboid and 3 cuneiform bones. On the calcaneus there is an eminence called the calcaneal tubercle. The arrangement of the tarsal bones is shown in Fig. 38. There are 5 metatarsal bones which are tubular. The bones of the toes (phalanges) are shorter than the corresponding phalanges of the fingers. Like the thumb, the big toe has two phalanges; all other toes have 3 phalanges each.

**Articulations of the bones of the leg.** The bones of the leg articulate with each other by means of joints. The largest of these joints are the hip joint, the knee joint and the ankle joint.

The hip joint (*articulatio coxae*) is formed by the acetabulum and the head of the femur (Fig. 39). This ball-and-socket joint allows flexion, extension, adduction, abduction, rotation and circumduction. Movement in the hip joint is somewhat more limited than in the shoul-

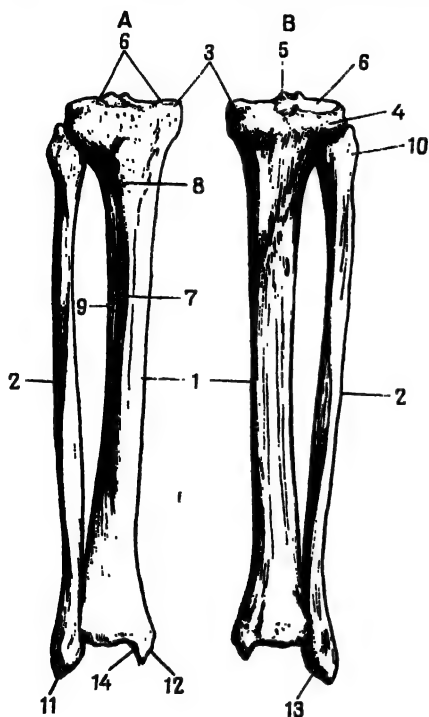


Fig. 36. Femur (right)

A—anterior aspect; B—posterior aspect; 1—head; 2—neck; 3—lesser trochanter; 4—greater trochanter; 5—linea aspera; 6—medial condyle; 7—lateral condyle; 8—intercondylar fossa; 9—lateral epicondyle; 10—medial epicondyle; 11—popliteal space; 12—surface for articulation with patella

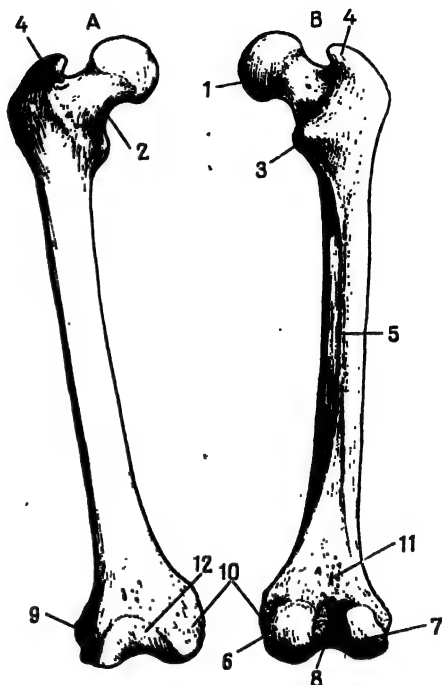


Fig. 37. Bones of shank (right)

A—anterior aspect; B—posterior aspect; 1—tibia; 2—fibula; 3—medial condyle; 4—lateral condyle; 5—intercondylar eminence; 6—articular surface for articulation with femur; 7—anterior crest; 8—tuberosity for muscular attachment; 9—interosseous ridge; 10—head of fibula; 11—malleolus of fibula; 12—malleolus of tibia; 13 and 14—articular surfaces of malleoli for articulation with talus

der joint. The joint capsule is reinforced by ligaments, the strongest of which is the iliofemoral ligament. It reinforces the joint capsule anteriorly and extends from the anterior inferior iliac spine to the intertrochanteric line (on the femur). This ligament is well developed in man because of his upright posture; it limits extension in the hip joint. Inside the joint there is a round ligament.

The knee joint (*articulatio genu*) is formed by 3 bones; femur, tibia and patella (Fig. 40). The special feature of this joint is its two intra-articular fibrocartilages or menisci, and two intra-articular cruciate ligaments. The joint capsule is reinforced by external ligaments. The synovial layer of the capsule forms folds inside the joint and also projections or synovial bursae. The joint is a hinge and ball-and-socket joint; it allows flexion and extension and, when flexed, slight rotation of the shank.

The bones of the shank are articulated by means of an interosseous membrane. The upper ends of these bones are additionally articulated by a gliding joint, and the lower ends by a ligament.

The ankle joint (*articulatio talocruralis*) is formed by the lower ends of the shank bones and the talus, with the malleoli of the tibia and fibula straddling the talus like a fork. This joint is a hinge joint.

The following joints are found in the foot: (1) talocalcaneal—between the talus and the calcaneus; (2) talocalcaneo-navicular; (3) Chopart's joint, which unites the talocalcaneo-navicular and the calcaneocuboid joints; (4) the joint between the navicular, cuneiform and cuboid bones; (5) tarsometatarsal joints which articulate the cuneiform and cuboid bones with the metatarsal bones; (6) metatarsophalangeal joints; (7) interphalangeal joints. All the joints of the foot are reinforced by ligaments.

The widest movements are possible in the upper (talocruralis) and lower (talocalcaneal and talocalcaneo-navicular) joints which are united under the name of the joint of the foot. The upper ankle joint allows dorsiflexion and plantar flexion. The lower ankle joint makes it possible to pronate and supinate the foot. Pronation raises the outer border of the foot and lowers the inner border; supination does the opposite. In this case the foot is also adducted and abducted. The movements in the upper and lower ankle joints may be combined.

The foot as a whole. The foot performs a predominantly supportive

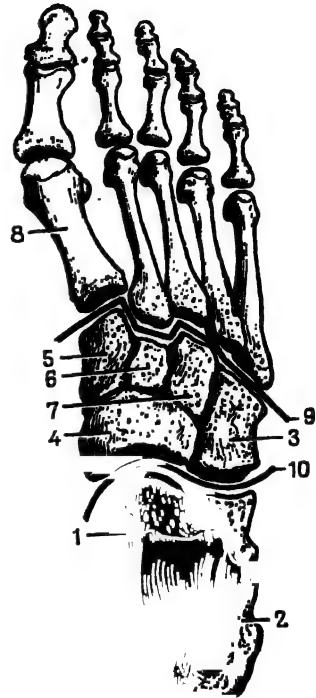


Fig. 38. Bones of right foot (superior aspect)

1—talus; 2—calcaneus; 3—cuboid; 4—navicular; 5, 6 and 7—cuneiform; 8—first metatarsal; 9 and 10—lines of articulations of bones

function; the bones of the foot are not arranged in one plane, but form longitudinal and transverse curves with their convexity towards the dorsal aspect and their concavity towards their plantar surface. These curves are known as the arches of the foot. There is a longitudinal arch and a transverse arch. In a standing position the foot rests on the calcaneal tuberosity and the heads of the metatarsal bones.

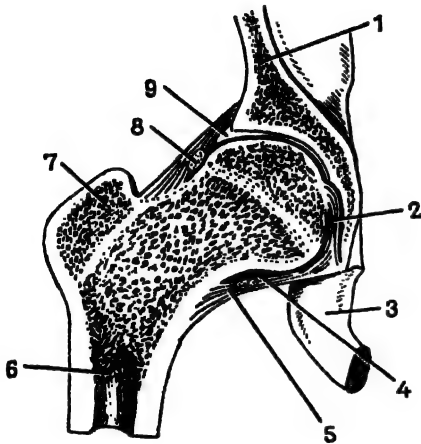


Fig. 39. Hip joint (section)

1—ilium; 2—round ligament; 3—ischium;  
4—neck of femur; 5—joint capsule; 6—femur;  
7—greater trochanter; 8—zona orbicularis; 9—glenoid lip

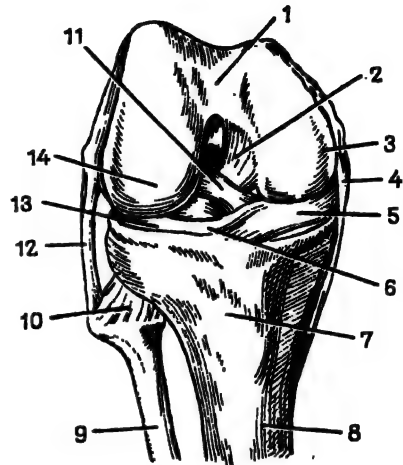


Fig. 40. Knee joint (right). Capsule removed, femur flexed (anterior aspect)

1—surface for articulation with patella;  
2 and 11—cruciate ligaments; 3 and 14—  
condyles of femur; 4 and 12—ligaments  
binding joint capsule; 5 and 13—menisci;  
6—ligaments articulating menisci; 7—tu-  
berosity of tibia; 8—tibia; 9—fibula; 10—  
ligament between head of fibula and tibia

The arches of the foot reduce jarring during movement. In some people the arches of the feet are flattened; this condition is called *flat foot* (pes planus).

## SKULL

The bony part of the head is called the **cranium** or **skull**. The skull (Fig. 41) has a cavity which contains the brain. The bones of the skull form the oral cavity, the nasal cavity, the orbits (eyesockets) which contain the organs of vision, and the cavities which contain the organs of hearing. Nerves and blood vessels pass through the numerous openings in the skull. The skull is usually divided into **cranial** and **facial** parts. The cranial part has a base and a dome or vault. It is

formed of two paired bones called the parietal and temporal bones, and four unpaired bones, the frontal, ethmoid, occipital and sphenoid bones. The facial skull is composed of six paired bones, namely the upper jaw or maxilla, zygoma, nasal, lacrimal, palate and inferior nasal concha (or inferior turbinate bones), and two unpaired bones called the vomer and lower jaw or mandible. The hyoid bone is regarded as a bone of the facial skull. The bones of the skull have different

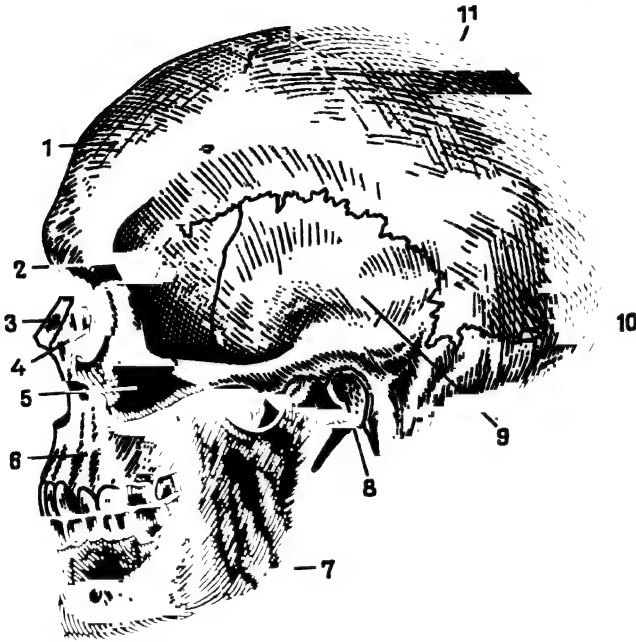


Fig. 41. Skull (lateral aspect)

1—frontal bone; 2—sphenoid bone (great wing); 3—nasal bone; 4—lacrimal bone; 5—zygoma; 6—maxilla; 7—mandible; 8—external acoustic meatus; 9—temporal bone; 10—occipital bone; 11—parietal bone

shapes. Some of the skull bones are characterized by the presence of air-filled cavities called **air sinuses**. Such cavities are present in the maxilla, ethmoid, frontal, sphenoid and temporal bones; they communicate with the nasal cavity except for the air sinuses of the temporal bone, which communicate with the nasopharynx.

### CRANIAL BONES

The **frontal bone** (os frontale) consists of a squama, two orbital parts and a nasal part (Fig. 42). There are paired eminences on the squama called frontal tuberosities and supra-orbital ridges. Anteriorly each



of the orbital parts ends in a supra-orbital margin. Inside the frontal bone there is an air sinus (frontal sinus) divided into two halves by a bony partition.

The ethmoid bone (*os ethmoidale*) consists of a horizontal or cribriform (perforated) plate, a perpendicular plate, two orbital plates and two labyrinths (see Fig. 44). Each labyrinth is formed by small



Fig. 42. Frontal bone (outer surface)

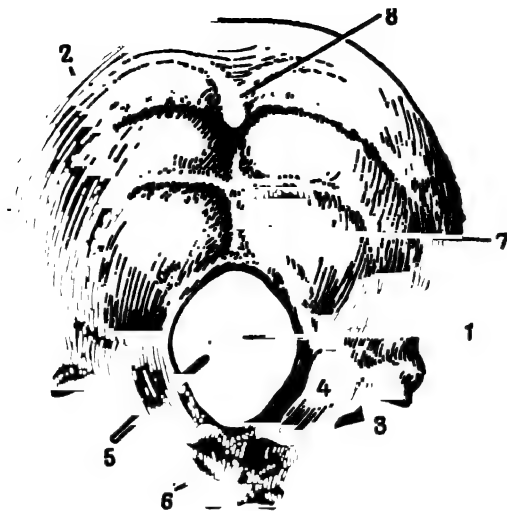
1—squama; 2—frontal tuberosity; 3—nasal part; 4—supra-orbital ridge; 5—supra-orbital margin; 6—temporal line

air sinuses, or air cells, divided by thin bony plates. Two curved bony plates, the superior and middle nasal conchae, are suspended from the inner surface of each labyrinth.

The parietal bone (*os parietale*) is a paired bone; it is shaped like a quadrilateral plate (Fig. 41). On its external surface it has an eminence called the parietal tuberosity.

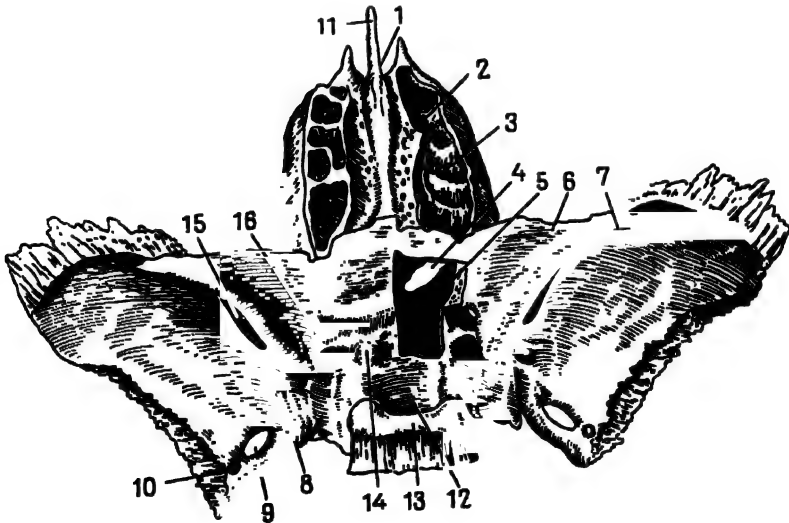
The occipital bone (*os occipitale*) consists of a squama, two lateral parts and a basal part (Fig. 43). These parts bound a large opening, the foramen magnum, through which the cranial cavity communicates with the vertebral canal. The body of the occipital bone is fused with the sphenoid bone, forming a slope with its upper surface. On the external surface of the squama there is an external protuberance called the inion. On each side of the foramen magnum there is a condyle; by means of these condyles the occipital bone articulates with the atlas. At the base of each condyle runs a canal for the hypoglossal nerve.

The sphenoid or basal bone (*os sphenoidale*) consists of a body and three pairs of processes: the great wings, the small wings and the pterygoid processes (Fig. 44). On the upper surface of the body is the so-called sella turcica with the hypophyseal fossa in which the hypo-



**Fig. 43. Occipital bone (outer surface)**

*1*—foramen magnum; *2*—squama; *3*—lateral part; *4*—condyle; *5*—canal for hypoglossal nerve; *6*—body (basal part); *7*—external occipital ridge; *8*—inion



**Fig. 44. Sphenoid (basal) and ethmoid bones**

*1*—crista galli; *2*—cribriform plate of ethmoid bone; *3*—labyrinth of ethmoid bone; *4*—opening leading to sphenoid sinus; *5*—sphenoid sinus; *6*—small wing; *7*—great wing; *8*—foramen rotundum; *9*—foramen ovale; *10*—foramen spinosum; *11*—perpendicular plate of ethmoid bone; *12*—sella turcica of sphenoid bone; *13*—back of sella turcica; *14*—tubercle of sella turcica; *15*—superior orbital fissure; *16*—optic canal

physis is lodged. There is an optic foramen in the base of each small wing. The wings (great and small) bound the superior orbital fissure. The great wings have three foramina: the rotundum, the ovale and the spinosum. Inside the body of the sphenoid bone there is an air sinus divided into two, by a bony partition.

The **temporal bone** (*os temporale*) is a paired bone; it consists of four parts; the squama, the petrous part (*pars petrosa*) or pyramid, the mastoid part and the tympanic part (Fig. 45). It contains the organ of hearing, the auditory tube, the carotid canal and the canal for the facial nerve. On the outside of the bone is the external acoustic meatus. To the front of it is the mandibular fossa for the articular process of the lower jaw. The squama gives rise to the zygomatic process which articulates with the temporal process of the zygomatic bone to form the zygomatic arch. The pyramid has three surfaces. On its posterior surface is the internal acoustic meatus which gives passage to the facial and acoustic nerves. The facial nerve leaves the temporal bone through the stylomastoid foramen. The long styloid process rises from the inferior surface of the pyramid. Inside the pyramid is the tympanic cavity (cavity of the middle ear) and the internal ear. The mastoid part has an eminence, called the mastoid process, which contains air cells. An inflammatory condition of the cells of the mastoid process is called mastoiditis.

### *Facial Bones*

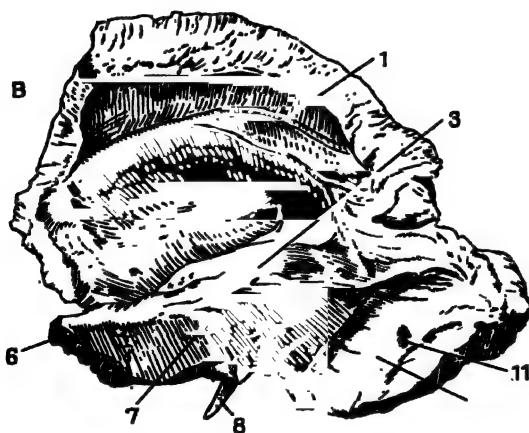
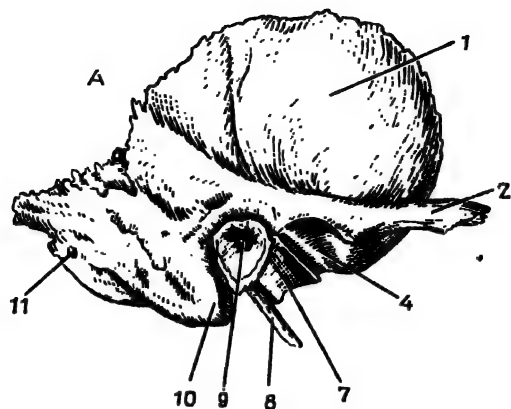
The **upper jaw** (*maxilla*) is a paired bone (Fig. 46). It consists of a body and four processes: the frontal, zygomatic, palatine and alveolar processes. There are four surfaces on the body of the maxilla: the anterior, posterior or infratemporal, superior or orbital and medial or nasal surfaces. There is a depression on the anterior surface called the canine fossa, and an eminence on the posterior surface called the maxillary tuberosity. The alveolar process has eight cells for the lodgment of the dental roots. Inside the body of the maxilla there is an air sinus called the maxillary sinus.

The **zygomatic bone** (*os zygomaticum*) (see Fig. 41) has the shape of an irregular quadrangle; it produces an eminence in the lateral part of the face and forms part of the zygomatic arch.

The **nasal bone** (*os nasale*) (see Fig. 41) is a rectangular plate of bone which forms part of the bridge of the nose.

The **lacrimal bone** (*os lacrimale*) (see Fig. 41) is a small bone; it has a lacrimal groove and a crest and forms part of the fossa of the lacrimal sac and the nasolacrimal canal.

The **palatine bone** (*os palatinum*) consists of horizontal and vertical plates, and forms part of the hard palate and lateral wall of the nasal cavity.



**Fig. 45. Temporal bone (right)**

*A*—external surface; *B*—internal surface; 1—squama; 2—zygomatic process; 3—anterior surface of pyramid; 4—articular fossa; 5—sigmoid sulcus; 6—apex of pyramid; 7(*A*)—tympanic part; (*B*)—internal acoustic meatus; 8—styloid process; 9—external acoustic meatus; 10—mastoid process; 11—mastoid foramen

The inferior concha is a thin curved plate of bone situated on the lateral wall of the nasal cavity. All the above bones of the facial skull are paired.

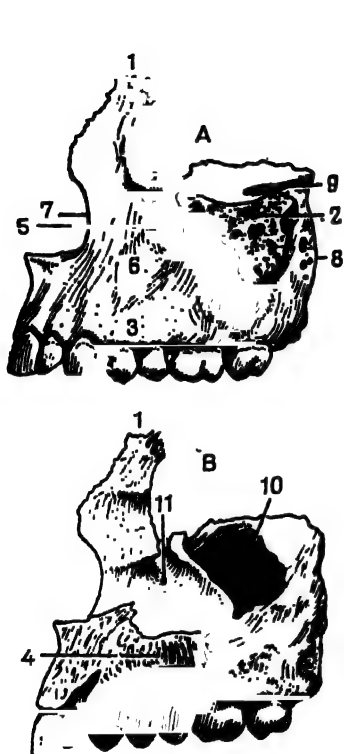


Fig. 46. Maxilla

A—left, external aspect; B—right, internal aspect; 1—frontal process; 2—zygomatic process; 3—alveolar process; 4—palatine process; 5—infraorbital foramen; 6—canine fossa; 7—nasal notch; 8—maxillary tuberosity; 9—infraorbital sulcus; 10—maxillary sinus; 11—lacrimal groove

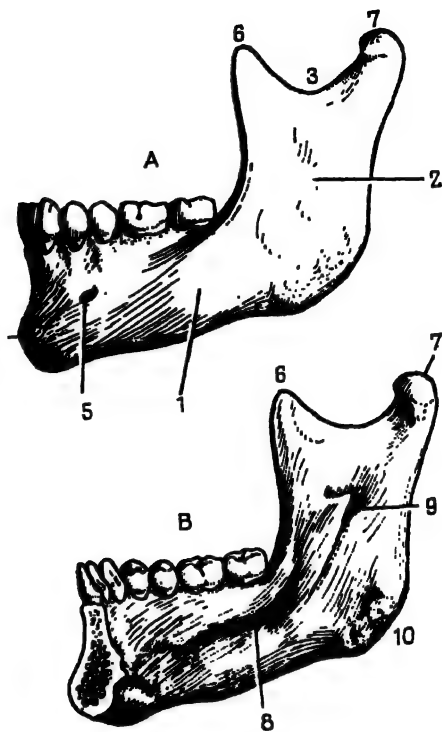


Fig. 47. Mandible

A—left half, external aspect; B—right half, internal aspect; 1—body; 2—branch; 3—notch; 4—mental protuberance; 5—mental foramen; 6—coronoid process; 7—articular process; 8—mylohyoid line; 9—mandibular angle; 10—mandibular angle

The vomer is an irregular quadrangular plate; it forms part of the nasal septum.

The mandible (lower jaw) is U-shaped and consists of a body and two branches (Fig. 47). The superior surface of the body is called the alveolar\* surface for it contains 16 cells (alveoli) for the dental roots.

\* Alveolus—socket, cell.

There are two mental tubercles and two mental foramina on the external surface of the body; there is a mental spine and the mylohyoid line on the internal surface. Each branch of the mandible arises from the body at an obtuse angle and ends on top in two processes, the coronoid and condyloid processes, which are separated by a notch. On the internal surface of each branch there is a mandibular foramen which leads to a similarly named canal. The lower jaw is the only mobile bone of the skull.

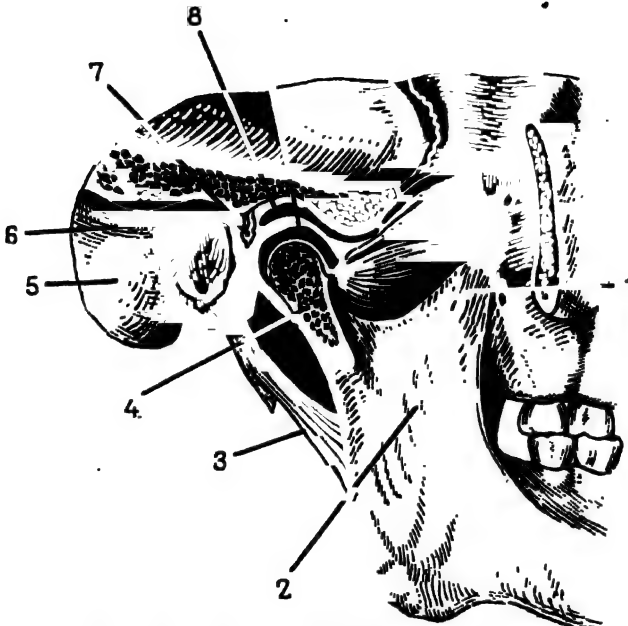


Fig. 48. Right mandibular joint (section)

1—coronoid process; 2—branch of mandible; 3—stylomandibular ligament; 4—articular process; 5—mastoid process; 6—external acoustic meatus; 7—joint capsule; 8—articular fossa; 9—disk

The **hyoid bone** (os hyoideum) is U-shaped and consists of a body and two pairs of cornua (greater and lesser). It is situated between the lower jaw and the larynx, and many muscles of the neck are attached to it.

### *Articulations of the Bones of the Skull*

All skull bones except the mandible articulate by means of sutures. The sutures are distinguished according to their shape as *dentate*, *squamosa* and *flat*. The articulation between the frontal and parietal

bones is an example of a dentate suture, that between the temporal and parietal bones is squamose, and those between the bones of the facial skull are flat. The most important sutures of the skull are as follows: the suture between the frontal and parietal bones is called the coronal suture, that between the two parietal bones is the sagittal suture, and that between the parietal and occipital bones is the lambdoid suture. In elderly people the sutures usually ossify.

**Mandibular or temporomandibular joint (Fig. 48).** The mandible articulates with the temporal bones by means of a combined temporomandibular or mandibular joint. This joint has an intra-articular cartilage or disk, and the joint capsule is reinforced by ligaments. The joint allows the following movements: raising and lowering, and forward, backward, and sideward displacement. All these movements are performed in chewing. The mandible rises and drops in speaking.

### *The Skull as a Whole*

The skull is divided into cerebral and facial parts. The upper part of the cerebral skull is called the **dome**, and the lower part is called the **base**. The anterior part of the base of the cerebral skull is covered from below by the bones of the facial skull. The dome of the skull is formed by the squama of the frontal bone, the parietal bones and the upper part of the squama of the occipital bone. The bones of the dome are flat. They consist of external and internal plates of a dense substance with a spongy substance in between.

The base of the skull is formed by the frontal, occipital, sphenoid and temporal bones. The base of the skull has *external* and *internal surfaces*.

The external surface of the base of the skull (Fig. 49) shows the foramen magnum, the condyles of the occipital bone, the canal for the hypoglossal nerve, the jugular foramen, the styloid process, the foramen of the carotid canal, the stylomastoid foramen, the pterygoid processes of the sphenoid bone and other structures. The internal surface of the base of the skull (Fig. 50) is divided into three cranial fossae, the anterior, middle and posterior fossae. It has the following parts and apertures: the cribriform plate of the ethmoid bone, the optic foramen, the superior orbital fissure, the sella turcica, the foramen rotundum, the foramen ovale and foramen spinosum, the foramen lacerum, the pyramid of the temporal bone, the internal acoustic meatus and other structures.

The internal surface of the bones of the cerebral skull has grooves for the lodgment of the venous sinuses of the dura, and recesses and indentations for the gyri and sulci of the brain.

Some of the skull bones (parietal bone, mastoid part of the temporal bone, etc.) have apertures which give passage to emissary veins thro-

ugh which the venous sinuses of the dura and the veins of the skull bones communicate with the subcutaneous veins of the scalp.

On the sides of the skull there are the temporal, infratemporal and pterygopalatine fossae. The temporal and infratemporal fossae lodge

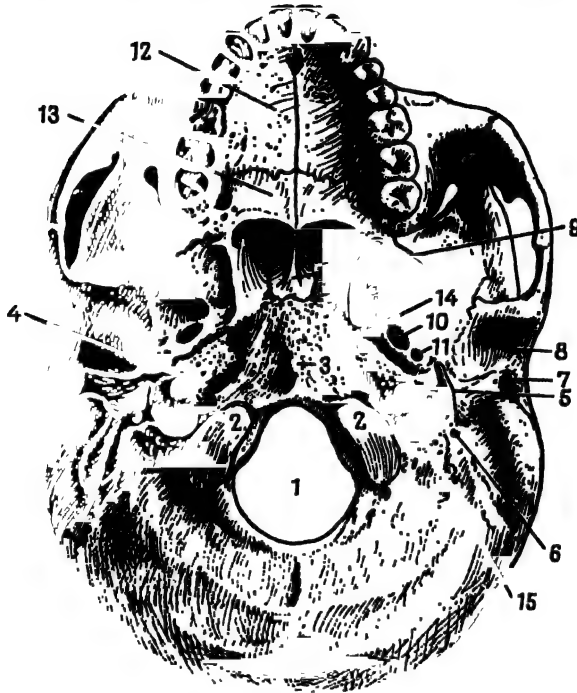


Fig. 49. External surface of base of skull

1—foramen magnum; 2—occipital condyles; 3—pharyngeal tubercle; 4—external opening of carotid canal; 5—styloid process; 6—stylomastoid foramen; 7—external acoustic meatus; 8—joint capsule; 9—vomer; 10—foramen ovale; 11—foramen spinosum; 12—palatine process of maxilla; 13—horizontal plate of palatine bone; 14—lacerated foramen; 15—jugular foramen.

muscles. The pterygopalatine fossa extends into the infratemporal fossa. It communicates with the cranial cavity through the foramen rotundum, with the nasal cavity through the sphenopalatine foramen, with the orbit through the inferior orbital fissure, and with the oral cavity through the pterygopalatine canal. Nerves and blood vessels pass through the pterygopalatine fossa.

The bones of the facial skull form the skeleton of the oral cavity, the nasal cavity and the orbit.

The oral cavity (cavum oris) has superior and anterolateral bony walls. The superior wall is the hard palate formed by the palatine



processes of the maxillae and the horizontal plates of the palatine bones. The anterolateral walls of the cavity are formed by the alveolar processes of the jaws and by the teeth.

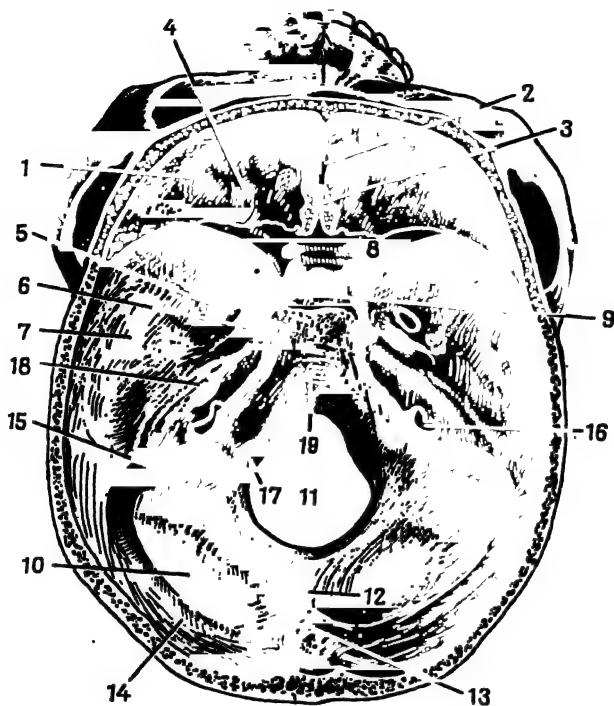


Fig. 50. Internal surface of base of skull

1—anterior cranial fossa; 2—crista galli; 3—cribriform plate of ethmoid bone; 4—orbital part of frontal bone; 5—foramen ovale; 6—lacerated foramen; 7—middle cranial fossa; 8—small wing; 9—sella turcica; 10—posterior cranial fossa; 11—foramen magnum; 12—internal occipital ridge; 13—internal occipital protuberance; 14—transverse sulcus; 15—sigmoid sulcus; 16—jugular foramen; 17—canal for hypoglossal nerve; 18—internal acoustic meatus; 19—slope

The nasal cavity (cavum nasi) has inferior, superior and two lateral walls and a septum. The inferior wall is the hard palate. The top of the nasal cavity is bounded by the nasal part of the frontal bone and the horizontal plate of the ethmoid bone. The lateral wall is formed by the upper jaw, the vertical plate of the palatine bone and the labyrinth of the ethmoid bone. The septum consists of the vomer and the perpendicular plate of the ethmoid bone, and divides the nasal cavity into right and left halves. The lateral wall of the nasal cavity gives off three curved bony plates called the superior, middle and inferior conchae, which divide each half of the nasal cavity into three

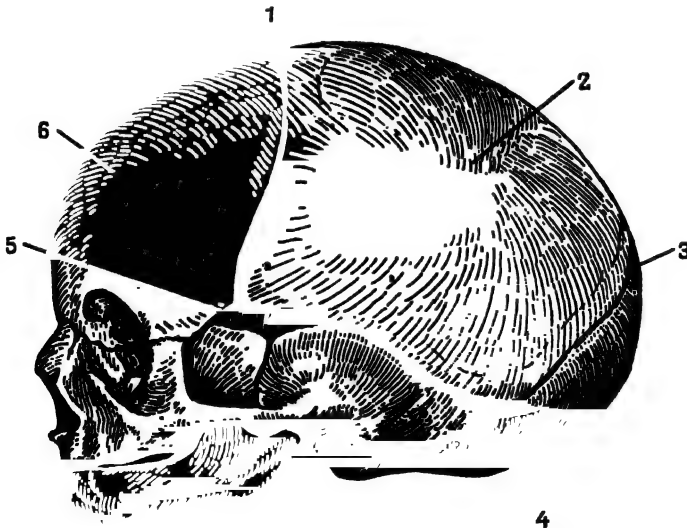
nasal passages: the superior, middle and inferior passages. In the skull the nasal cavity has one anterior and two posterior orifices. The anterior orifice is called the piriform orifice. The posterior orifices are known as choanae; through them the nasal cavity communicates with the nasopharynx. All the air sinuses except the air cells of the mastoid process open into the nasal cavity.

The orbit has four walls: the superior, inferior, external and internal walls. The superior wall is formed by the orbital part of the frontal bone, and the inferior wall by the orbital surface of the maxilla. The external wall is formed by the zygomatic bone and the great wing of the sphenoid bone, and the internal wall by the lacrimal bone and the orbital plate of the ethmoid bone. The optic foramen and superior orbital fissure lead from the orbit into the cranial cavity; the inferior orbital fissure leads into the pterygopalatine fossa; the nasolacrimal canal leads into the nasal cavity.

The orbit contains the eyeball and the lacrimal gland. The posterior part of the eyeball is surrounded by cellular tissue which gives passage to the nerves and blood vessels and lodges the eye muscles.

### *Age Characteristics of the Skull*

The bones of the dome of the skull and all the bones of the facial skull, except the inferior concha, go through two stages of develop-



**Fig. 51. Skull of the newborn**

1—anterior fontanelle; 2—parietal tuberosity; 3—posterior fontanelle; 4—posterior lateral fontanelle; 5—anterior lateral fontanelle; 6—frontal tuberosity

ment: membranous and osseous. The other skull bones go through three stages: membranous, cartilaginous and osseous. In the dome of the skull of newly born child there are unossified vestiges of the membranous skull called fontanelles (Fig. 51).

Altogether there are six fontanelles: anterior, posterior, lateral and two posterior lateral. The largest fontanelle is the anterior fontanelle, and the posterior fontanelle is next. The anterior fontanelle is at the point of union of the frontal, sagittal and coronal sutures, and is rhombic in shape. This fontanelle ossifies at the age of 18 months. The posterior fontanelle is at the point of junction of the lambdoid and sagittal sutures. It is much smaller than the anterior fontanelle and ossifies at the age of 2 months. The other fontanelles ossify soon after birth. Some diseases, for example rickets, cause the fontanelles to ossify later.

Compared with the cerebral skull the facial skull of the newly born child is less developed than that of the adult. The air sinuses of the skull bones are undeveloped. There are no teeth. In old people the sutures ossify and the layer of spongy substance of the skull bones diminishes. After the teeth fall out the cells of the alveolar processes atrophy.

The female skull is relatively smaller than the male one, and its tuberosities and other eminences are less pronounced.

## *Muscular System.* *Physiology of Muscles*

### GENERAL INFORMATION

Muscles are the active part of the motor apparatus; their contractions produce various movements. Functionally all muscles are divided into two groups: voluntary and involuntary muscles.

**Voluntary muscles** consist of striated muscle tissue and contract by the will of man. This group includes all the muscles of the head, trunk and extremities, i.e., the skeletal muscles, as well as those of some internal organs (tongue, larynx, etc.).

**Involuntary muscles** consist of smooth (nonstriated) muscle tissue and are found in the walls of internal organs, blood vessels and in the skin. The contractions of these muscles are not controlled by man.

It should be remembered that the heart muscle, although its contractions are not controlled by the will, consists of striated muscle tissue with a special structure (p. 215).

There are more than 400 skeletal muscles in the human organism; in adults they make up about two-fifths of the total body weight.

Skeletal muscles are complex in structure. They consist of muscle fibres of different lengths (up to 12 cm); the fibres are usually parallel to each other and are united in bundles. Each muscle is composed of many such bundles. The various muscle bundles and the muscle as a whole have thin connective tissue sheaths. In addition, a group of muscles or individual muscles are invested with denser bands of connective tissue known as fasciae. There are tendons at the ends of muscles by means of which they are attached to bones.

**Tendons** consist of dense fibrous connective tissue and are not contractile. An expanded tendon consisting of a fibrous or membranous sheet is called an *aponeurosis*.

In addition to muscle fibres and connective tissue each skeletal

muscle has blood vessels and nerves. Blood passes along the blood vessels, delivers nutrients to the muscles and carries away their waste products. The nerves link the muscles and the central nervous system. Muscles have both motor and sensory nerve fibres; impulses (signals) about the state of the muscle are transmitted to the brain along sensory fibres. This form of sensitivity is called muscle sense. The nerve impulses which cause the muscle to contract are transmitted from the

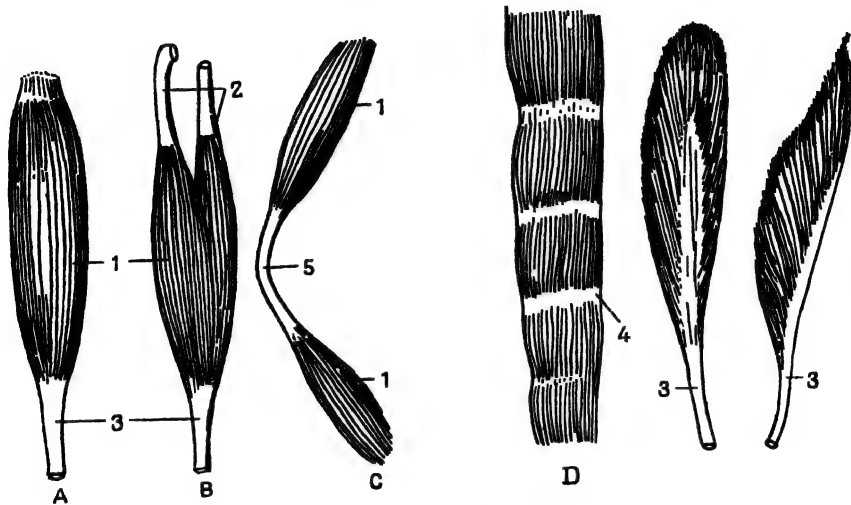


Fig. 52. Shapes of muscles

A—fusiform; B—bicipital; C—digastric; D—muscle with tendinous cross-bands; E—bipennate; F—pennate; 1—belly of muscle; 2 and 3—tendons of muscles; 4—tendinous cross-band; 5—intermediate tendon

brain along motor fibres. Injury to the nerves which innervate muscles causes disturbances in voluntary movements (muscular paralysis).

Muscles are called *long*, *short* and *broad* according to their size and shape. Long muscles are found mainly in the extremities, and vary in structure (Fig. 52). Broad muscles are found in the trunk, and short muscles are found between the ribs and the vertebrae.

Nearly all muscles extend over one, two or more joints; when they contract they cause the joints to move. The most common types of movement are flexion, extension, abduction, adduction, and rotation. Usually the muscles causing flexion are in front of the joints, while those that bring about extension are behind the joints. Only in the knee and ankle joints do the anterior muscles cause extension and the posterior muscles cause flexion. Muscles situated on the lateral aspect of joints perform the function of abduction, while those situa-

ted on the median aspect of joints perform the function of adduction. Rotation is effected by muscles situated obliquely or transversely to the vertical axis.

In an anatomical study of muscles the terms *origin* and *insertion* of muscles are used. The former refers to the end of the muscle which remains fixed during contraction; the latter term refers to the movable end of the muscle. When the position of the body and its different parts is altered these points will change places in most muscles, i.e., the fixed points will become movable and vice versa. In defining the functions of muscles the latter are conventionally divided into *agonists* and *antagonists*. Agonists are contracting muscles engaged in the movement of a part, while antagonists are muscles which act in opposition to them. For example, several muscles take part in flexing the trunk; all these muscles are agonists. Other muscles extend the trunk; these muscles are antagonists of the flexors. The work of various groups of muscles is co-ordinated. For example, when flexors contract extensors relax. As a result the movements of the various parts of the human body are performed smoothly. Most movements (walking, running, etc.) involve many muscles, the contractions and relaxations of the different groups taking place in a definite order and with a definite force. It is a manifestation of the *co-ordination of movements* which is effected by the nervous system. Some diseases are characterized by disorder of the co-ordination of movements; in such cases the smooth character of the movements is disturbed and the movements become disproportionate and jerky. When two or more muscles co-operate to produce a movement that neither could effect alone these muscles are called *synergists*, and their combined, co-operative action is called *synergy*.

**Fasciae.** A fascia is a dense band of connective tissue which binds a muscle or group of muscles. Fasciae differ in thickness in the different regions of the body. They are usually named after the site in which they are situated (fasciae of the shoulder, of the forearm, etc.). The fascia of one region is continuous with the fascia of another region. The connective tissue sheaths formed by the fasciae for the muscles prevent sideward displacement of the muscles. The famous Russian scientist N. Pirogov made a considerable contribution to the theory of fasciae in the human body.

## MUSCLES AND FASCIAE OF THE HEAD

Most of the head muscles are situated in the region of the face.

The dome of the skull, under the scalp, is covered by a broad tendon, the galea aponeurotica, which closely adheres to the scalp but loosely to the periosteum. It is the origin of the frontalis muscle and the insertion of the occipitalis muscle. When these muscles contract the

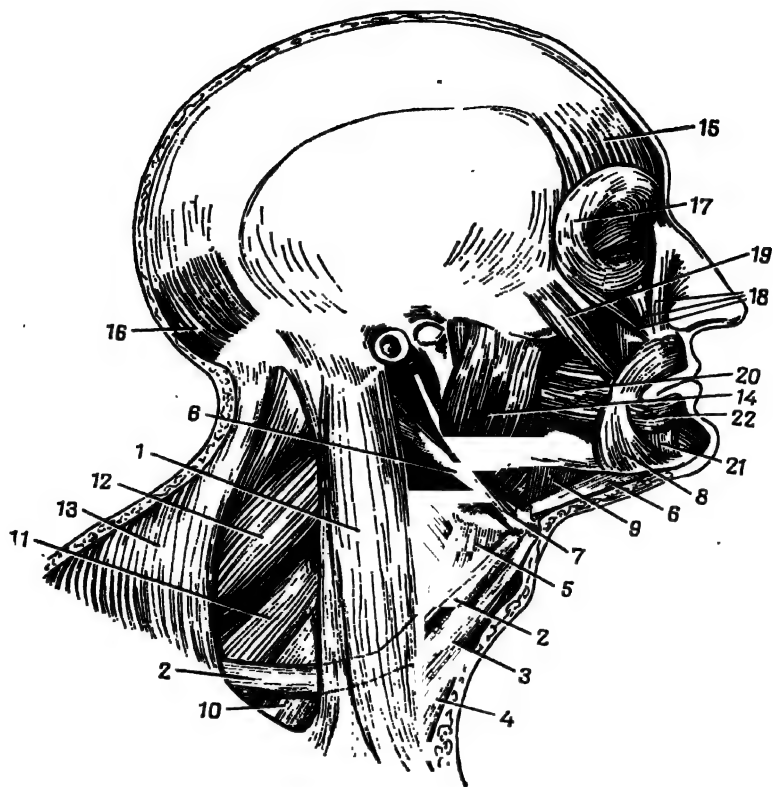


Fig. 53. Muscles of head and neck (lateral aspect)

1—sternocleidomastoid; 2—omohyoid; 3—sternohyoid; 4—sternothyroid; 5—thyrohyoid;  
 6—biventer cervicis; 7—stylohyoid; 8—triangularis; 9—geniohyoid; 10—scalenus  
 anterior; 11—scalenus medius; 12—levator scapulae; 13—trapezius; 14—masseter;  
 15—frontalis; 16—occipitalis; 17—orbicularis oculi; 18—quadratus labii superioris; 19—  
 zygomatic; 20—buccinator; 21—quadratus labii inferioris; 22—orbicularis oris

*galea aponeurotica* (together with the scalp) moves forward and backward. The muscles of the face are divided into two groups: the mimetic muscles (or muscles of facial expression) and the muscles of mastication.

The **mimetic muscles** or muscles of facial expression (Fig. 53) have their origin in the skull bones and their insertion in the skin. Contraction of these muscles changes the expression of the face. The largest mimetic muscles are the *frontalis*, the *orbicularis oculi*, the *orbicularis oris*, the *buccinator*, the *quadratus labii inferioris* and the *quadratus labii superioris*.

The **frontalis muscle** is situated under the skin in the region of the forehead and extends from the *galea aponeurotica* to the skin of the eyebrows. The muscle raises the eyebrows and forms transverse wrinkles on the skin of the forehead.

The **orbicularis oculi muscle** is situated round the palpebral fissure and its contraction closes the eye.

The **orbicularis oris muscle** is situated round the mouth, which closes when the muscle contracts.

The **buccinator muscle** is situated in the cheek; when it contracts the cheeks are pressed to the teeth. There is adipose tissue (fat pad) on the buccinator muscle which rounds out the cheeks.

The muscle that on contraction raises the upper lip (*quadratus labii superioris*) originates on the maxilla and the zygoma, and is inserted in the skin of the upper lip in the region of the nasolabial fold.

The muscle that on contraction lowers the lower lip (*quadratus labii inferioris*) originates on the lower jaw and is inserted in the skin of the lower lip.

There are several other smaller muscles of facial expression: the *zygomaticus* (pulls the corner of the mouth upward and outward), the *triangularis* (pulls the corner of the mouth downward and outward), the *corrugator supercilii* (knits the eyebrows), the *risorius* (muscle of laughter), etc. The muscles of facial expression are not enclosed in well defined fasciae.

The **muscles of mastication** are attached at both ends to skull bones, one end necessarily to the lower jaw. The contractions of these muscles control movements of the lower jaw in mastication and in speech. There are four pairs of masticatory muscles: the *masseter*, the *temporalis*, the *pterygoideus lateralis* and the *pterygoideus medialis*.

The **masseter muscle** (see Fig. 53) extends from the zygomatic arch to the external surface of the corner of the lower jaw, and raises the lower jaw (closes the mouth). This muscle and the parotid gland situated behind it are covered with a dense fascia (*fascia parotidea masseterica*).



The **temporalis muscle** occupies the entire temporal fossa, extends downwards medially inside the zygomatic arch and is inserted into the coronoid process of the lower jaw; it raises the lower jaw and the posterior bundles retract it. The temporalis muscle has a dense fascia.

The **pterygoideus lateralis muscle** is situated in the infratemporal fossa; it extends from the pterygoid process of the sphenoid bone to the articular process of the mandible and displaces the mandible to the opposite side. When this muscle contracts on both sides it protrudes the lower jaw.

The **pterygoideus medialis muscle** extends from the pterygoid process of the sphenoid bone to the medial surface of the corner of the lower jaw and raises the lower jaw. Thus the muscles of mastication raise the lower jaw and move it forward, backward and to the sides. The lower jaw is lowered by muscles of the neck situated between the lower jaw and the hyoid bone.

### MUSCLES AND FASCIAE OF THE NECK

The muscles of the neck (see Fig. 53) may be divided into 4 groups: (1) the platysma myoides; (2) the sternocleidomastoid muscle; (3) muscles situated above and below the hyoid bone; (4) deep muscles of the neck.

1. The **platysma myoides** muscle is a thin, broad band of muscle situated under the skin on the lateral surface of the neck. On contraction, it stretches the skin of the neck and lowers the corners of the mouth.

2. The **sternocleidomastoid** muscle is the largest muscle of the neck, extending from the clavicle and sternum to the mastoid process. The muscle bends the head to the side (simultaneously turning the face to the opposite side). When the muscle contracts on both sides the head is thrown back.

3. The muscles of the neck situated above the hyoid bone lower the mandible and, if the mandible is fixed, raise the hyoid bone and the larynx. Such movements occur in chewing and swallowing.

Four muscles are situated above the hyoid bone: (1) the *biventer cervicis* consisting of two bellies connected by an intermediate tendon; the anterior belly is attached to the mandible, the intermediate tendon is attached to the hyoid bone, and the posterior belly is attached to the mastoid process; (2) the *mylohyoid*, which extends from the mandible to the hyoid bone, forming the inferior wall, or diaphragm of the oral cavity; (3) the *geniohyoid*, extending from the mental spine of the mandible to the hyoid bone; (4) the *stylohyoid*, extending from the styloid process of the temporal bone to the hyoid bone. This muscle participates only in raising the hyoid bone.

The following muscles of the neck are situated below the hyoid

bone: (1) the *sternohyoid*, extending from the sternum to the hyoid bone; it lowers the hyoid bone; (2) the *sternothyroid*, extending from the sternum to the thyroid cartilage; it lowers the thyroid cartilage and the larynx; (3) the *thyrohyoid*, extending from the thyroid cartilage to the hyoid bone; it raises the thyroid cartilage or lowers the hyoid bone; (4) the *omohyoid*, extending from the superior margin of the scapula to the hyoid bone and consisting of two bellies with an intermediate tendon; it lowers the hyoid bone.

4. The deep muscles of the neck include the three scalenus muscles (anterior, middle and posterior), the longus colli and the longus capitis. The *scalenus* muscles have their origin in the cervical vertebrae and their place of insertion on the first (scalenus anterior and middle) and second (scalenus posterior) ribs. These muscles raise the ribs and thereby participate in inhalation (in forced respiration). There is a space between the anterior and middle muscles called the *scalenus interspace* which contains blood vessels and nerves.

The *longus colli* and *longus capitis* muscles are situated on the anterior surfaces of cervical vertebrae. On contraction the longus colli flexes the cervical part of the vertebral column and the longus capitis flexes the head.

**Fasciae of the neck.** There are three fasciae in the neck, the *superficial*, *middle* and *deep* fasciae. The superficial fascia is very thin; it invests the platysma myoides. The middle fascia invests the sternocleidomastoid muscle, all muscles above and below the hyoid bone, forms the capsule of the submaxillary gland and is connected with the veins of the neck. When the omohyoid muscle contracts, this fascia tenses and the veins in the neck dilate helping to move the blood towards the heart.

The deep fascia of the neck covers (anteriorly) the deep muscles of the neck and the cervical part of the spine.

## MUSCLES AND FASCIAE OF THE CHEST

The muscles of the chest (Plate I) are divided into 2 groups:

- (1) the muscles inserted on the bones of the upper extremity (pectoralis major, pectoralis minor, subclavius, and serratus anterior);
- (2) the proper muscles of the chest (external and internal intercostal).

The *pectoralis major* muscle is situated superficially on the anterior chest wall. Its origin is on the sternum and clavicle and its insertion is on the intertubercular sulcus of the humerus. It adducts the arm and, if the latter is fixed, elevates the ribs; if the arm is raised, it pulls the arm downward.

The *pectoralis minor* muscle is situated under the pectoralis major muscle and extends from the second-fifth ribs to the coracoid process

of the scapula; it draws the scapula downward and forward. If the scapula is fixed, it elevates the ribs.

The **subclavius** muscle extends from the first rib to the clavicle; when it contracts it pulls the clavicle downward and medially.

The **serratus anterior** muscle is situated on the lateral surface of the thorax; it originates in the form of saw teeth on the eight upper ribs and its insertion is on the inferior angle and vertebral border of



Fig. 54. Diaphragm (inferior aspect)

1—tendinous centre; 2, 5 and 6—pedicles of lumbar part; 3—opening for oesophagus; 4—opening for aorta; 7—costal part; 8—thoracic part; 9—opening for inferior vena cava

the scapula. The muscle draws the scapula forward and outward and turns it (the arm may be adducted to a vertical position).

The **external** and **internal intercostal** muscles are situated in the spaces between the ribs. The external intercostal muscles elevate the ribs and thereby participate in inhalation, while the internal intercostal muscles depress the ribs and thus participate in exhalation.

**Fasciae of the chest.** There are three fasciae in the pectoral region: *superficial*, *deep* and *endothoracic*. The superficial fascia covers the pectoralis major and serratus anterior muscles. The deep fascia lies under the pectoralis major and covers the pectoralis minor and exter-

nal intercostal muscles. The endothoracic fascia lines the walls inside the thoracic cavity.

The diaphragm is usually described with the muscles of the chest.

The diaphragm (Fig. 54), an unpaired muscle, separates the thoracic cavity from the abdominal cavity and is therefore called the thoracoabdominal partition. It is a thin musculotendinous dome-shaped and upwardly convex band. Its central part consists of a tendon and is called the tendinous centre. The diaphragm has origins on the sternum, ribs and lumbar vertebrae, and so it is considered in three parts. The lumbar part in its turn is divided into right and left halves with three crura each. The diaphragm has three large openings: for the aorta and oesophagus in the lumbar part, and for the inferior vena cava in the tendinous centre. The diaphragm participates in respiration. It descends when it contracts, with the result that the capacity of the thorax increases, the lungs expand and an inhalation takes place. When the diaphragm relaxes it resumes its former position (rises), the capacity of the thorax decreases and an exhalation results.

### MUSCLES AND FASCIAE OF THE ABDOMEN

The muscles of the abdomen include the obliquus abdominis externus, obliquus abdominis internus, transversus abdominis, rectus abdominis and quadratus lumborum. They are situated between the bones of the thorax and pelvis and form part of the walls of the abdominal cavity. The obliquus abdominis externus and internus and the transversus abdominis muscles are broad flat muscles with corresponding tendons, or aponeuroses.

The obliquus abdominis externus muscle (see Plate I) has its origin on the eight lower ribs and extends downward towards the median line. The hindmost bundles of muscle are inserted on the iliac crest, while the others merge into the aponeurosis. The lower border of the aponeurosis is turned in to form a groove and is called the inguinal (Poupart's) ligament. It extends from the anterior superior spine of the ilium to the pubic tubercle.

The obliquus abdominis internus muscle (Fig. 55) is situated under the obliquus abdominis externus and has its origin on the iliac crest and the inguinal ligament. The muscle bundles are spread out, with the upper bundles being inserted on the lower ribs, and the rest merging into the aponeurosis.

The transversus abdominis muscle (Fig. 55) is situated under the obliquus abdominis internus and has its origin on the cartilages of the six lower ribs, the iliac crest and the inguinal ligament. The muscle bundles run transversely, extend to the median line and merge into the aponeurosis.

The **rectus abdominis** muscle (Fig. 55) is situated laterally of the median line and extends from the cartilages of the fifth-seventh ribs to the pubic bone. The muscle is crossed by 3-4 tendinous bands. It lies in a tendinous sheath which is formed by the aponeuroses of the obliquus abdominis externus and internus muscles, and the transversus abdominis muscle.

The **quadratus lumborum** muscle is situated between the twelfth

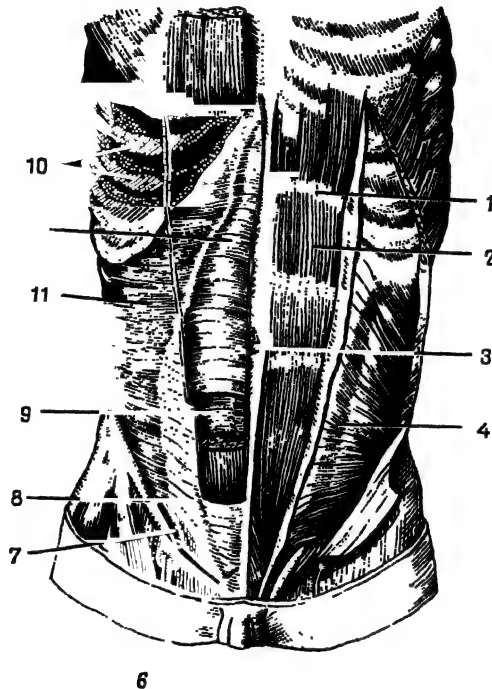


Fig. 55. Abdominal muscles. Right: obliquus abdominis are removed and rectus abdominis is transected; left: obliquus abdominis externus is removed

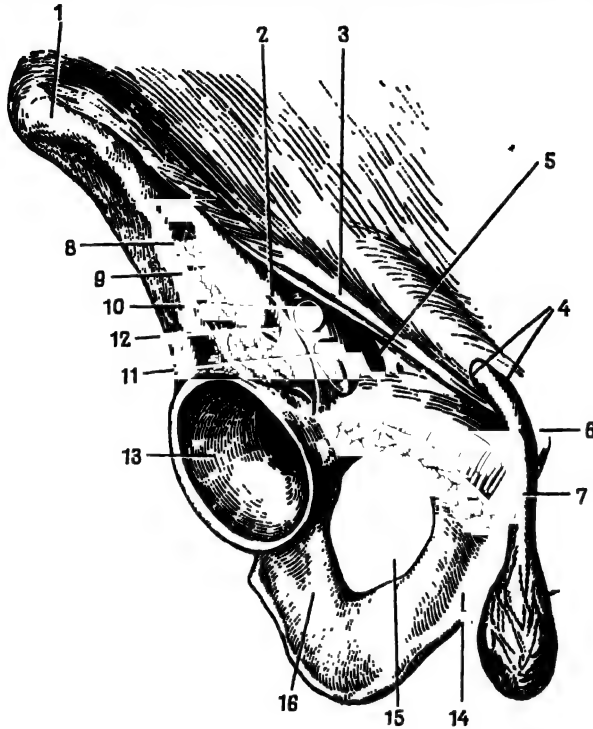
1—tendinous cross-band; 2—rectus abdominis; 3—umbilicus; 4—obliquus abdominis internus; 5 and 6—sheath of rectus abdominis; 7—spermatic cord; 8—inguinal ligament; 9—transverse abdominal fascia; 10—intercostals; 11—transversus abdominis

rib and the iliac crest; it forms part of the posterior wall of the abdominal cavity and flexes the lumbar division of the vertebral column.

The muscles of the anterior abdominal wall and the diaphragm form the so-called prelum abdominale. When they contract they increase the pressure within the abdominal cavity and thereby help in defaecation, urination and parturition. Since these muscles are connected with the ribs they also take part in respiration. When the rec-

tus and obliquus abdominis muscles contract they bring the thorax closer to the pelvis, i.e., flex the trunk. The obliquus abdominis muscles also participate in turning the trunk.

**Fasciae of the abdomen.** The obliquus externus muscle is covered with a thin fascia. The walls of the abdominal cavity are lined with



**Fig. 56. Inguinal region (male)**

1—Ilium (anterior superior spine); 2—Iliopectineal ligament; 3—inguinal ligament; 4—subcutaneous inguinal opening; 5—Internal opening of femoral canal; 6—pubic tubercle; 7—spermatic cord; 8—lacuna musculorum (space); 9—Iliopectineal muscle; 10—femoral artery; 11—femoral vein; 12—femoral nerve; 13—acetabulum; 14—pubic bone; 15—obturator foramen; 16—Ishium

a fascia called the endoabdominal or transversalis fascia, and are covered with the peritoneum. There are places in the abdominal wall through which viscera (for example, intestinal loops) sometimes penetrate from the abdominal cavity to the skin, i.e., hernias are formed. These parts include the inguinal canal, the linea alba, the navel, etc.

**Inguinal canal.** The inguinal canal is a slitlike space about five centimetres long (Fig. 56). It is situated above the inguinal ligament

which forms its lower wall. Anteriorly the canal is bounded by the aponeurosis of the obliquus abdominis externus muscle, superiorly by the inferior borders of the obliquus internus and the transversus abdominis, and posteriorly by a fascia. The male inguinal canal contains the spermatic cord, and the female inguinal canal contains the round ligament of the uterus (see Chapter 6, "Urogenital System"). The canal has two openings; the deep inguinal (or abdominal inguinal) ring and the subcutaneous inguinal (or external abdominal) ring. The subcutaneous inguinal ring is situated under the skin just above the pubic tubercle; it is a triangular slit in the aponeurosis of the obliquus abdominis externus muscle. The deep inguinal ring is situated on the posterior surface of the anterior abdominal wall just above the middle of the inguinal ligament; it is a funnel-like recess with edges formed by the endoabdominal fascia.

In male infants the testes descend from the lumbar region through the inguinal canals into the scrotum.

The *linea alba abdominis* is a raphe of tendinous fibres of the aponeuroses of the obliquus abdominis externus and internus and the transversus abdominis muscles of the right and left sides along the median line of the anterior abdominal wall. The linea alba abdominis extends from the xiphoid process of the sternum to the pubic symphysis.

The *navel* (umbilicus) is situated roughly in the middle of the linea alba abdominis. It is a scar formed by the closure of the umbilical ring of the child after birth. The inguinal ring of the foetus transmits the cord.

### MUSCLES AND FASCIAE OF THE BACK

The muscles of the back are divided into two groups: (1) muscles with insertions on the bones of the upper extremity (trapezius, latissimus dorsi, rhomboideus, and levator scapulae);

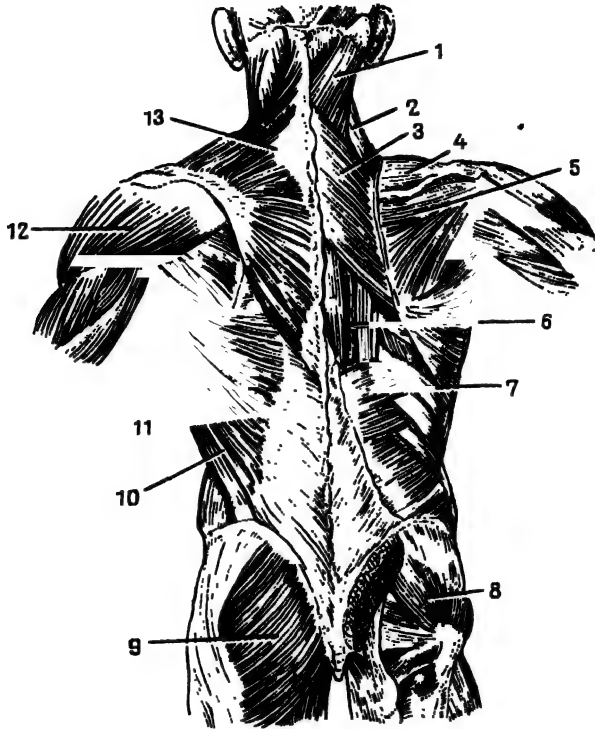
(2) proper muscles of the back (serratus posterior and inferior, splenius, sacrospinalis, etc.).

The **trapezius** muscle (Fig. 57) is a broad flat muscle situated under the skin in the upper part of the back. Its origin is on the occipital bone, nuchal ligament and spinous processes of the thoracic vertebrae, and its insertion is on the spina scapulae and the clavicle. The muscle consists of three parts—superior, middle and inferior. The superior part raises the scapula, the middle part draws the scapula towards the spine, and the inferior part lowers the scapula. Contraction of the whole muscle draws the scapula to the spine.

The **latissimus dorsi** (Fig. 57) is a flat muscle situated under the skin in the lower part of the back and the lateral part of the thorax. Its origin is on the six lower thoracic vertebrae, the lumbodorsal

fascia and the iliac crest, and it is inserted on the intertubercular sulcus of the humerus. It adducts the arm and depresses the raised arm.

The **rhomboideus** muscle (Fig. 57) is situated in the upper part of the back under the trapezius muscle. Its origin is on the two lower



**Fig. 57. Muscles of back. Left: first layer; right: second layer**  
 1—splenius; 2—levator scapulae; 3—rhomboideus; 4—supraspinatus; 5—infraspinatus;  
 6—sacrospinalis; 7—serratus posterior inferior; 8—gluteus medius; 9—gluteus maximus;  
 10—latissimus dorsi; 11—lumbodorsal fascia; 12—deltoides; 13—trapezius

cervical and four upper thoracic vertebrae, and its insertion is on the vertebral margin of the scapula; it draws the scapula towards the spine.

The **levator scapulae** is situated on the lateral surface of the neck under the superior part of the trapezius muscle and extends from the four upper cervical vertebrae to the medial angle of the scapula; it elevates the scapula. The proper muscles of the back are deep muscles.

The **serratus posterior superior** muscle lies under the rhomboideus muscle and extends from the spinous processes of the two lower cer-



vical and two upper thoracic vertebrae to the upper ribs (second to fifth); it elevates the ribs and takes part in respiration.

The **serratus posterior inferior** muscle lies under the latissimus dorsi and extends from the lumbodorsal fascia to the four lower ribs; it depresses the ribs and participates in respiration.

The **splenius** muscle (Fig. 57) of the head and neck (*splenius capitis* and *splenius cervicis*) is situated on the posterior surface of the neck under the trapezius muscle. When it contracts it extends the head; contraction on one side only turns the head to that side.

The **sacrospinalis** (Fig. 57) is a powerful muscle situated to the side of the vertebral column; it extends from the sacrum to the occipital bone. The muscle extends the vertebral column and is therefore also called the *rectus spinalis*. Several more layers of short muscles are situated deeper than the sacrospinalis muscle.

**Fasciae of the back.** The trapezius and latissimus dorsi muscles are covered with a thin fascia. In the lower part of the back is the so-called lumbodorsal fascia (Fig. 57). It is rhomboid in shape and, like an aponeurosis, is firmly fused with the spinous processes of the lumbar vertebrae and the medial sacral crest. The lumbodorsal fascia consists of two layers with the sacrospinalis muscle lodged in between. The broad abdominal muscles have part of their origin on this fascia.

### MUSCLES OF THE SHOULDER GIRDLE

There are six muscles in the shoulder girdle: *deltoideus*, *supraspinatus*, *infraspinatus*, *subscapularis*, *teres major* and *teres minor* (Plates I and II).

The **deltoideus** muscle extends from the *spina scapulae* and the clavicle to the deltoid tuberosity of the humerus and abducts the humerus to a horizontal position. The anterior bundles of the muscle flex the shoulder and the posterior bundles extend it.

The **supraspinatus** muscle lies in the supraspinous fossa and its insertion is on the greater tubercle of the humerus; together with the *deltoideus* muscle it abducts the shoulder.

The **infraspinatus** muscle lies in the infraspinous fossa and its insertion is on the greater tubercle of the humerus; it rotates the shoulder outward.

The **subscapularis** muscle lies in the subscapular fossa and its insertion is on the lesser tubercle of the humerus; it rotates the shoulder inward.

The **teres major** muscle extends from the scapula to the intertubercular sulcus of the humerus and rotates the shoulder inward.

The **teres minor** muscle extends from the scapula to the greater tubercle of the humerus and rotates the shoulder outward.

**MUSCLES OF THE ARM**

The muscles of the arm are divided into those of the upper arm, forearm and hand. The muscles of the upper arm are divided into anterior and posterior muscles.

The **anterior group** is composed of three muscles:

(1) the **biceps brachii**, situated superficially on the upper arm, has its origin in two heads (long and short) on the scapula, and its insertion is on the tuberosity of the radius. Part of this muscle's tendon is a dense fibrous plate situated in the olecranon fossa and merges into the fascia of the forearm. The muscle flexes the arm in the shoulder and elbow joints;

(2) the **brachialis** muscle lies under the biceps brachii and extends from the humerus to the coronoid process of the ulna; it flexes the elbow joint;

(3) the **coracobrachialis** muscle extends from the coracoid process of the scapula to the humerus and flexes and adducts the arm.

The **posterior group** of muscles is composed of the **triceps brachii** which originates with one of its heads (long) on the scapula and two of its heads on the humerus, and has its insertion on the olecranon process of the ulna; it extends the elbow joint.

Two groups of muscles, anterior and posterior, are distinguished on the forearm. Most of the anterior muscles have their origin on the medial epicondyle of the humerus, and the posterior muscles have theirs on the lateral epicondyle.

The **anterior group** consists of the following muscles:

(1) **two flexors of the wrist joint**; the **flexor carpi radialis** and the **flexor carpi ulnaris**. The former has its insertion on the second and third metacarpal bones, and the latter on the pisiform bone;

(2) **two flexors of the fingers**; the **flexor digitorum sublimis** and the **flexor digitorum profundus**. Each of these muscles has four tendons extending to the phalanges of the second to fifth fingers;

(3) **flexor pollicis longus** (long flexor of the thumb) extending to the ungual phalanx of the thumb; .

(4) **two pronating muscles** (muscles rotating the radius and hand inward), the **pronator teres** and the **pronator quadratus**, inserted on the radius.

The **posterior group** consists of the following muscles:

(1) **three extensors of the wrist** (one ulnar and two radial); the **extensor carpi radialis brevis**, the **extensor carpi radialis longus**, and the **extensor carpi ulnaris**, with their insertions on the metacarpal bones.

(2) **extensor digitorum communis** of the hand, divided into four tendons extending to the phalanges of the second to fifth fingers; it extends the fingers;

- (3) two extensors of the thumb, the **extensor pollicis longus** and the **extensor pollicis brevis** extending to the phalanges of the thumb;  
 (4) **abductor pollicis longus** extending to the first metacarpal bone; it abducts the thumb;

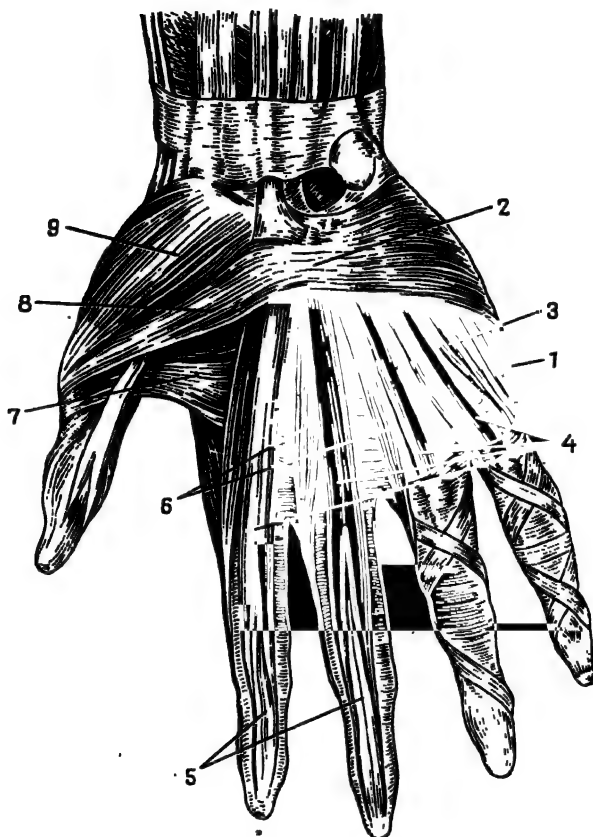


Fig. 58. Muscles of hand

1—abductor digiti quinti; 2—transverse carpal ligament; 3—flexor digiti quinti brevis; 4—tendons of flexor digitorum sublimis; 5—tendons of flexor digitorum profundus; 6—vermiculate muscles; 7—adductor pollicis; 8—flexor pollicis brevis; 9—abductor pollicis brevis

(5) **supinator** (rotating the radius and hand outward), with its insertion on the radius; it supinates the hand.

On the lateral surface of the forearm is the **brachioradialis** muscle extending from the lateral surface of the lower third of the humerus to the radius; the muscle participates in flexing the elbow joint and rotating the radius.

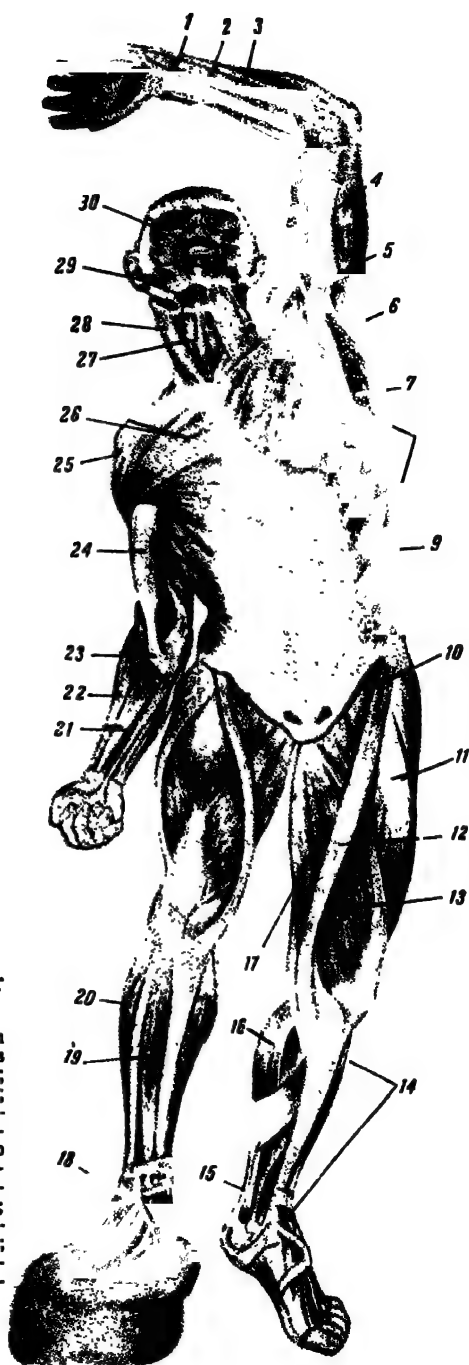


Plate I. Human muscles (anterior aspect)

1—palmaris longus; 2—flexor digitorum sublimis; 3—flexor carpi ulnaris; 4—triceps brachii; 5—coracobrachialis; 6—teres major; 7—latissimus dorsi; 8—serratus anterior; 9—obliquus abdominis externus; 10—iliopsoas; 11 and 13—quadriceps femoris; 12—sartorius; 14—tibialis anterior; 15—tendo calcaneus; 16—gastrocnemius; 17—gracilis; 18—inferior ligament holding extensors; 19—tibialis anterior; 20—peroneal; 21—flexor carpi radialis; 22—brachioradialis; 23—fibrous plate; 24—biceps brachii; 25—deltoides; 26—pectoralis major; 27—sternohyoid; 28—sternocleidomastoid; 29—masseter; 30—orbicularis oculi

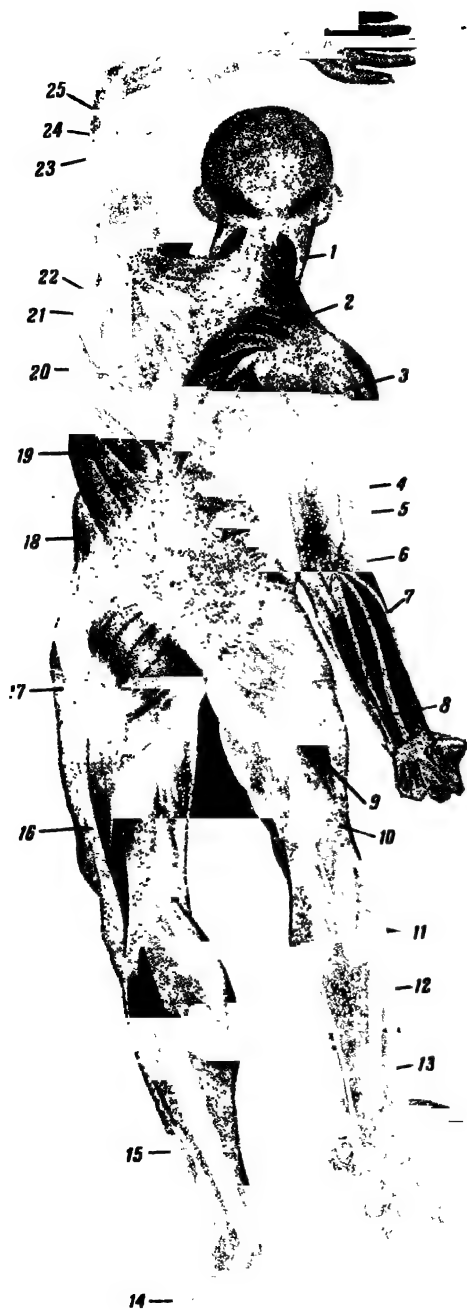


Plate II. Human muscles (posterior aspect)

1—sternocleidomastoid; 2—trapezius; 3—deltoides; 4—triceps brachii; 5—biceps brachii; 6—brachioradialis; 7—extensor carpi radialis longus; 8—extensor digitorum communis (of hand); 9—gluteus maximus; 10—biceps femoris; 11—gastrocnemius; 12—soleus; 13 and 15—peroneus longus; 14—extensor digitorum longus (of foot) (tendon); 16—part of fascia lata; 17—tensor fasciae latae; 18—obliquus abdominis externus; 19—latissimus dorsi; 20—rhomboides; 21—teres major; 22—infraspinatus; 23—triceps brachii; 24—brachialis; 25—biceps brachii

The names of the anterior and posterior muscles of the forearm indicate the movements they perform.

The muscles of the hand (Fig. 58) are situated on the palmar surface and are divided into three groups: (1) **thenar muscles**, (2) **middle group** and (3) **hypothenar muscles**.

The thumb has four short muscles; a **flexor** and **abductor**, and **adductor** and an **opponens**.

The middle group of hand muscles consists of four **vermiculate muscles** (which flex the proximal phalanges and extend the middle and unguis phalanges), three **palmar interossei** (they adduct the fingers) and four **dorsal interossei muscles** (they abduct the fingers).

The little finger has the following muscles: **palmaris brevis**, **flexor digiti quinti brevis** (of hand), **abductor digiti quinti** (of hand) and **opponens digiti quinti** (of hand).

**Fasciae.** The fasciae of the shoulder girdle muscles are well marked.

The fascia of the upper arm invests all the muscles of the upper arm and, in addition, forms two quite dense **intermuscular septa** called the **internal** and **external septa**. The latter separate the anterior group of upper arm muscles from the posterior group.

The fascia of the forearm is not uniform. In the upper part of the forearm it includes tendinous fibres of superficial muscles. At the boundary with the hand it forms an annular thickening in which the palmar and dorsal ligaments of the carpus are distinguished. These ligaments give off connective tissue septa and fibrous canals (six canals under the dorsal ligament and two under the palmar ligament of the carpus) are formed as a result. The fibrous canals are lined with a synovial membrane which forms so-called synovial sheaths for the tendons of the muscles extending from the forearm to the hand. The synovial sheaths contain synovial fluid which helps to reduce friction during contraction of the muscles.

The fascia on the palmar aspect of the hand is a dense band called the **palmar aponeurosis**. The fascia on the dorsal aspect is relatively feebly defined.

On the palmar aspect of each finger there is an **osseofibrous canal** which contains the tendons of the muscles (flexors of the fingers) enclosed in synovial sheaths. The synovial sheaths of the flexors of the first and fifth fingers enclose the tendons of these muscles in the region of the hand and reach the carpus.

The axilla and the cubital fossa are of great practical importance on the upper extremity.

The axilla is bounded anteriorly by the **pectoralis major muscle**, posteriorly by the **subscapularis muscle**, externally by the upper end of the humerus and adjacent muscles of the upper arm, and internally by the **serratus anterior muscle**. The axilla is filled with loose

cellular tissue which holds nerves, blood vessels and a large number of lymph nodes.

The cubital fossa is situated in front of the elbow joint between the brachioradialis and pronator teres muscles. The brachial artery lies under a band of fibres, while the subcutaneous layer lodges superficial veins.

### MUSCLES OF THE PELVIS

The muscles of the pelvis are divided into internal muscles (iliopsoas, piriformis and obturator internus) and external muscles (three gluteus muscles, obturator externus, quadratus femoris and the tensor fasciae latae).

The iliopsoas muscle originates in two parts on the lumbar vertebrae and the iliac fossa, extends to the femur under the inguinal ligament and has its insertion on the lesser trochanter of the femur. The muscle flexes the hip joint and rotates the femur outward. When the leg is fixed it flexes the lumbar part of the spine.

The piriformis muscle has its origin on the anterior surface of the sacrum and runs out of the true pelvis through the greater sciatic foramen.

The obturator internus muscle has its origin on the hip bone around the obturator foramen and runs out of the true pelvis through the lesser sciatic foramen. The piriformis and obturator internus muscles have their insertions on the greater trochanter of the femur and rotate the femur outward.

The gluteus maximus muscle (see Fig. 57) has its origin on the lateral surface of the ilium and the sacrum and its insertion on the gluteal tuberosity of the femur; it extends the hip joint, and when the legs are fixed it extends the trunk.

The gluteus medius and gluteus minimus muscles have their origin on the lateral surface of the ilium and their insertion on the greater trochanter of the femur; both muscles abduct the femur.

The obturator externus muscle has its origin on the hip bone around the external aspect of the obturator foramen; the quadratus femoris muscle has its origin on the ischial tuberosity. The insertions of both muscles are on the greater trochanter of the femur; the muscles rotate the femur outward.

The tensor fasciae latae has its origin on the anterior superior iliac spine and waves into the broad fascia of the femur; it tenses this fascia.

### MUSCLES OF THE LEG

The muscles of the leg are divided into the muscles of the thigh, the muscles of the shank and the muscles of the foot.

There are three groups of muscles—anterior, posterior and medial—

on the thigh. The anterior group consists of the quadriceps femoris and the sartorius muscles.

The quadriceps femoris is a powerful muscle; it includes the rectus femoris and the three vastus muscles. The rectus femoris has its origin on the anterior inferior iliac spine, and the three vastus muscles on the femur. Lower down, all four muscles merge into a common tendon which embraces the patella and has its insertion on the tuberosity of the tibia. The lower part of the tendon of this muscle is called the patellar ligament. Tapping this ligament with a special (reflex) hammer produces the so-called patellar reflex. The quadriceps femoris muscle is an extensor of the knee joint.

The sartorius muscle, the longest muscle in the human body, has its origin on the anterior superior iliac spine. It extends obliquely downward and inward and its insertion is on the tibia near its tuberosity. The muscle participates in flexion of the hip and knee joints.

The posterior group consists of three muscles: the semitendinosus, the semimembranosus and the biceps femoris. All three muscles have their origin on the ischial tuberosity. The semitendinosus and semimembranosus muscles have insertions on the tibia, and the biceps femoris on the fibula. These muscles extend the hip joint and flex the knee joint. When the knee joint is flexed the biceps rotates the shank outward, and the other two muscles rotate it inward.

The internal group of thigh muscles consists of five muscles: the pectineus, the gracilis and three adductor muscles—*longus*, *brevis* and *magnus*. The origins of these muscles are on the pubis and ischium and their insertions are on the femur (except for that of the gracilis, which is on the tibia); all of them adduct the leg.

There are three groups of muscles on the shank: *anterior*, *posterior* and *lateral*. All muscles of the shank extend to the foot.

The anterior group consists of three muscles: the tibialis anterior, the extensor digitorum longus (of the foot) and the extensor hallucis longus. The tibialis anterior muscle dorsiflexes and inverts the foot, while the other two extend the toes.

The posterior group includes four muscles: the triceps surae, the tibialis posterior, the flexor digitorum longus and the flexor hallucis longus. The triceps surae is a very powerful muscle; it lies near the surface and actually consists of two muscles—the gastrocnemius and the soleus muscles. These two muscles form a common tendon (tendo calcaneus or achillis) with an insertion on the posterior surface of the calcaneus. The triceps surae muscle flexes the ankle joint (it raises the heel when a person stands on his toes). Under the triceps surae are the tibialis posterior, flexor digitorum longus and the flexor hallucis longus muscles. These muscles extend behind the internal malleolus to the foot. The tibialis posterior plantar flexes and inverts the foot; the two other muscles flex the toes.



The lateral group consists of two muscles: the peroneus longus and the peroneus brevis. These muscles extend from the shank to the foot, skirting the external malleolus. They evert and flex the foot.

**Muscles of the foot.** These muscles are divided into dorsal and plantar muscles. There is one muscle on the dorsum of the foot, the extensor digitorum brevis (of the foot), which has five tendons for the five toes. The muscles on the sole of the foot are divided into three groups—medial, lateral and middle. The medial group consists of three muscles: the flexor hallucis brevis, the abductor hallucis and the adductor hallucis. The lateral group is also composed of three muscles: the flexor digiti quinti brevis (of the foot), the abductor digiti quinti (of the foot) and the opponens digiti quinti (of the foot). The middle group includes the flexor digitorum brevis (which flexes the toes), four vermiculate muscles (which flex the proximal phalanges), three plantar interossei muscles (which adduct the toes) and four dorsal interossei muscles (which abduct the toes). The names of most of the muscles of the foot clearly indicate their functions.

**Fasciae.** The internal muscles of the pelvis are enclosed in a fascia which lines the abdominal cavity (endo-abdominal fascia). The gluteal muscles are situated in a well marked fascia which gives off connective tissue processes to the gluteus maximus muscle; these processes separate the muscle bundles from each other.

The fascia of the thigh is known as the fascia lata. It is the strongest fascia in the human body. On the lateral surface of the thigh it forms a thickening in the shape of a broad band. The fascia lata gives off three intermuscular fascial septa which separate the three groups of thigh muscles from each other. On the anterior surface of the thigh, below the inguinal ligament, there is an area (fossa ovalis) where the fascia lata is thin. Here the fascia gives passage to the great saphenous vein and lymph vessels. This portion of the fascia is called the lamina cribrosa.

The fasciae of the shank invest all the muscles of the shank. The fascia forms a thickening at the lower part of the shank called the superior ligament, which holds the extensor muscles. Near the ankle joint the tendons of the shank muscles which extend to the foot are enclosed in synovial sheaths. There are three synovial sheaths on the anterior surface of the joint, and three behind the internal malleolus; behind the external malleolus there is the common peroneal sheath.

The fascia is thin on the dorsum of the foot, but near the ankle joint it thickens to form the inferior ligament which holds the extensor muscles. The plantar fascia is a very dense band called the *plantar aponeurosis*.

The femoral triangle, femoral canal and the popliteal fossa are of great practical importance on the lower extremities.

**Femoral triangle.** The femoral triangle is bounded superiorly by the inguinal ligament, laterally by the sartorius muscle, and medially by the adductor longus muscle. It carries the largest blood vessels of the thigh: the femoral artery and vein, the deep femoral artery and vein and the terminal part of the great saphenous vein.

**Femoral canal.** The femoral canal is situated in the region of the femoral triangle, below the medial part of the inguinal ligament. Normally it does not exist, but forms only in cases of femoral hernia, i.e., when the viscera protrude under the skin of the thigh. The femoral canal is about two centimetres long. Its walls are formed by two layers of the fascia lata and the femoral vein. Normally, when there is no hernia, the small space between these structures is occupied by cellular tissue and lymph vessels. The canal has two openings—medial and lateral. The medial opening is bounded by the medial end of the inguinal ligament and the pubic bone and is enclosed in the fascia and peritoneum. The lateral opening corresponds to the indentation on the fascia lata known as the fossa ovalis; it is situated in the upper part of the thigh.

**Popliteal fossa.** The popliteal fossa is situated on the posterior surface of the knee joint. It is bounded at the sides by the tendons of the posterior thigh muscles and the two heads of the gastrocnemius muscle. It carries large blood vessels (popliteal artery and vein) and nerves (common peroneal and tibial) lodged in cellular tissue.

## PHYSIOLOGY OF MUSCLES

### MAIN PROPERTIES OF MUSCLES

Muscular tissue, like all other tissues, possesses the property of **excitability**, i.e., the ability to respond to stimulation and become active. The main function of muscular tissue, which distinguishes it from other tissues, is **contraction**, i.e., shortening. A contracting muscle shortens and becomes thicker, but its volume barely changes. Muscles can do work when they contract.

In the organism muscles become active and contract under the influence of nerve impulses which reach them from the central nervous system along motor nerves. As has already been noted, the contraction of striated muscles is controlled consciously (voluntary movements), whereas smooth muscles move involuntarily.

Muscles also possess the property of **tensility**, i.e., the ability to stretch (to a certain limit). When the cause producing the stretching of the muscle disappears, the muscle resumes its former state; this property is called **elasticity**.

*Methods of Studying Muscles*

In laboratories the physiologic properties of muscles are often studied on so-called neuromuscular preparations (isolated muscle) using special apparatus. For example, the contractions of an isolated muscle are recorded by means of a *myograph*. This apparatus consists of a support with clamps and a pen arm (Fig. 59). The free end of

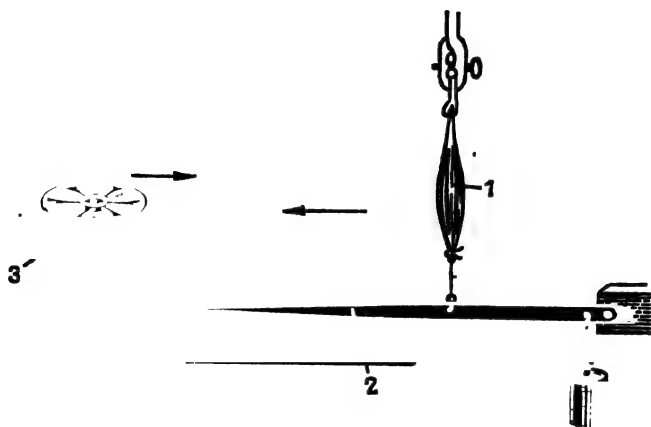


Fig. 59. Recording curve of muscular contraction  
1—gastrocnemius muscle; 2—pen arm; 3—kymograph cylinder

the pen arm is brought close to a rotating cylinder with a smoked surface (*kymograph*). The neuromuscular preparation is taken from a frog's hind leg. It consists of the gastrocnemius muscle, its sciatic nerve and the femur to which the muscle is fastened. One end of the muscle is clamped to the myograph and the other end is attached to the pen arm. The muscle can be made to contract by direct stimulation or by stimulation through the nerve; it is usually stimulated by electric current from an induction coil (the use of this apparatus means that the current strength can be regulated). When the muscle contracts the free end of the pen arm will draw a curve of muscular contraction. This curve is called a *myogram* (Fig. 59). The functional properties of a muscle in an intact organism are studied by using other instruments and apparatus, some very complex. These instruments and apparatus make it possible to determine the working capacity of muscles (*ergograph*), to study the action potentials arising in the muscles (*electromyograph*), etc.

## MUSCULAR CONTRACTION

A muscle will contract only if the stimulation is of a certain strength. The lowest limit of stimulus capable of evoking a response in a muscle is called the **threshold** or **liminal stimulus**. A stimulus weaker than threshold (which fails to evoke a contraction of the muscle) is called **subliminal**, and a stimulus stronger than threshold is called **supraliminal**.

The degree of contraction of a muscle depends to a certain extent on the strength of the stimulus. This is because the muscle fibres which make up a muscle possess different degrees of excitability; some contract in response to a weak stimulus (high excitability), and others in response to a stronger stimulus (low excitability). An increase in the strength of the stimulus (above threshold) will therefore be accompanied by an increase in the degree of muscular contraction.

In studying the contractions of skeletal (striated) muscles it is customary to distinguish between a single muscular contraction and a prolonged contraction (contracture) or tetanus.

A *single muscular contraction* may only be produced artificially in a laboratory on a neuromuscular preparation. It arises in response to a single brief stimulus (one impulse). The myogram of a single muscular contraction (Fig. 60 A) shows three periods. The muscle always begins to contract some time after the application of the stimulus. The first period, between the application of the stimulus and the beginning of muscular contraction, is called the **period of latent excitation** or the **latent period**. For human muscles this period is measured in thousandths of a second. It is followed by the second period, the **period of contraction** or **shortening of the muscle**. The third period is called the **period of relaxation of the muscle**.

The excitability of a muscle varies during a single contraction. For example, during the latent period the muscle is at first unexcitable (*refractory*); during the period of contraction its excitability gradually increases and reaches a higher level than in the state of rest (*exaltation phase*); finally, during the period of relaxation, its excitability decreases and returns to the initial level for the period of rest.

Not single, but maintained, tetanic contractions of skeletal muscles take place in the intact organism. Tetanic contractions result from the fact that in the organism stimuli reach the muscles from the central nervous system not as single impulses, but as a rapid succession of impulses. Maintained tetanic contraction depends on the frequency of the impulses. If the length of time between impulses is greater than the duration of a single contraction (0.1 sec), a series of single muscular contractions results (Fig. 60, B-I). If the frequency of impul-

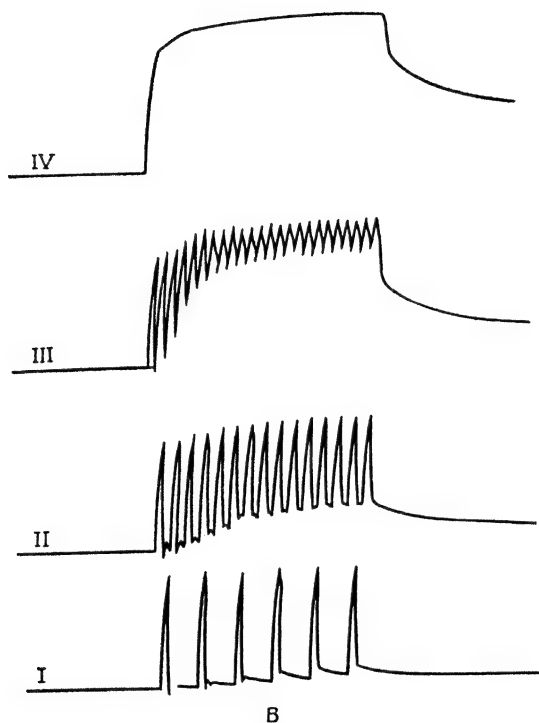
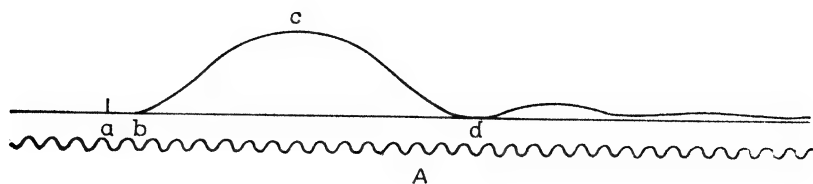


Fig. 60. *A*—curve of single muscular contraction (twitch)  
*a*—moment of stimulation; *b*—beginning of contraction; *ab*—latent period; *bcd*—curve of contraction;

*B*—various types of tetanus

*I*—single contractions; *II* and *III*—dentate (incomplete) tetanus; *IV*—smooth (complete) tetanus

ses is greater and each subsequent impulse reaches the muscle at the moment when it is relaxing, the contraction assumes the form of an incomplete tetanus (Fig. 60, *B-II* and *III*). If the impulses continue to increase in frequency, they will reach the muscle during the exaltation phase. This will give rise to a complete tetanus characterized by continuous contraction (Fig. 60, *B-IV*). The frequency of impulses is so great that a new excitation begins in the muscle before the preceding excitation has ended. Thus it can be seen that the form of the muscular contraction depends on the frequency of impulses, and the value of the contraction depends on the strength and frequency of the stimuli.

It was established by N. Vvedensky that there is a best, or optimum, rhythm of stimulation which gives the greatest degree of contraction (height of tetanus). The optimum rhythm varies for the different human skeletal muscles and ranges between 100 and 200 impulses per second.

**Muscle tone.** In the living organism muscles are never completely relaxed even at rest. Any muscle is usually in a state of certain tension or tone. Muscle tone is brought about by infrequent impulses reaching the muscle from the central nervous system. During tone contractions of muscles their metabolism is not noticeably increased, as in tetanic contractions. The body owes its stability and position to muscle tone.

### METABOLISM IN MUSCLES

Intensive metabolism takes place in working muscles, accompanied by complex chemical transformations with liberation and expenditure of a large amount of energy; some chemical reactions occur without participation of oxygen (anoxic or anaerobic phase), while other reactions require oxygen (oxygenous or aerobic phase).

In the anaerobic phase complex phosphorus compounds (adenosinetriphosphoric acid, etc.) are broken down with liberation of a large amount of energy. This energy is used in muscular contractions.

Glycogen is broken down at the same time. The liberated energy is used for the resynthesis of the phosphorus compounds from the products of their splitting. In the anaerobic phase glycogen is broken down to give lactic acid.

In the aerobic phase part of the lactic acid is broken down to give water and carbon dioxide as end products. At the same time energy is liberated and used to transform the other part of the lactic acid back into glycogen; the resynthesized glycogen is used for the resynthesis of the phosphorus compounds. Thus, as a result of chemical processes in the anaerobic and aerobic phases only one-third of the glycogen is broken down into end products and two-thirds of it is

resynthesized. As both glycogen and phosphorus compounds are resynthesized, the muscles use up these substances and energy more economically.

### **CHARACTERISTICS OF SMOOTH MUSCLES**

Smooth muscles are situated in the walls of hollow internal organs (stomach, intestines, bladder, etc.) and blood vessels. The main functional characteristics of smooth muscles, compared with striated muscles, are as follows.

The latent period of excitation is longer in smooth than in striated muscles. The stimulation threshold is higher in smooth muscles, and their excitability is consequently lower. Smooth muscles contract more slowly and for a longer period than striated muscles.

Smooth muscles may be in a state of prolonged contraction, but this is not tetanus which is characteristic of striated muscles. During prolonged or tonic contraction of smooth muscles their metabolism does not greatly change, as in tetanus of skeletal muscles. It should be noted that metabolism in smooth muscles is less intensive than in striated muscles. Smooth muscles possess greater tensility than striated muscles, which is very important for the functions of organs whose capacity may change greatly (bladder, uterus). Not only the capacity of the hollow internal organs, but also the movement of their contents (for example, of the food through the digestive tract) depends on the contraction of smooth muscles.

### **WORK OF MUSCLES**

When muscles contract they do work. Any quantity of work is measured in kilogram-metres (kgm), i.e., is expressed by the product of the load (in kg) and the height (in m) to which it is lifted. The work of muscles depends on their strength and length. The strength of a muscle is directly proportional to the cross-section of all the muscle fibres forming the given muscle. In other words, the thicker the muscle, the greater the load which it can lift. The height to which a load can be lifted depends on the length of the muscle. Consequently, the thicker and longer the muscle, the more work it can do.

### **MUSCULAR FATIGUE**

A muscle cannot work incessantly. During prolonged and uninterrupted work it gradually loses its working capacity. This state is known as muscular fatigue. In muscular fatigue the strength of muscular contraction decreases and the contractions become slower. Muscular fatigue is characterized by a longer latent period of muscular

excitation and reduced excitability of the muscles involved. The onset of muscular fatigue depends on the frequency of muscular contractions; excessively frequent contractions produce rapid fatigue. The duration of muscular efficiency also depends on the work load. An optimum frequency of contraction and an optimum work load can be found for every muscle to enable it to retain its working capacity for the longest possible period. Hence it can be seen that the work load and rhythm of movement influence the working capacity of a person doing physical work and, consequently, the amount of work done.

A decrease in the working capacity of muscles depends on neural and chemical factors. Fatigue first develops in the nervous centres which regulate muscular work, and then in the endings of motor nerves in muscle fibres (synapses). The result is that the character of the impulses reaching the muscles from the nervous system is altered, resulting in a decrease in the strength and speed of muscular contractions. Special experiments and observations have shown that the rapidity of onset of muscular fatigue depends on the state of the nervous system. It is well known, for example, that psychic and emotional factors (music, singing) influence man's working capacity.

The chemical factor involves the fact that in the working muscle the metabolites (lactic acid, etc.) are not completely oxidized because there is an insufficient supply of oxygen. Accumulation of these metabolites fosters the development of muscular fatigue.

In an intact organism the working capacity of muscles depends on the functional state of many systems of organs; cardiovascular, respiratory, endocrine, etc.

Systematic training (exercise) plays an important part in increasing working capacity. Physical training brings about changes not only in the muscles (their development and resultant increase in strength), but also in all the other systems of organs; for example, it strengthens the cardiovascular and respiratory systems. All this improves the health and increases endurance. I. Sechenov pointed out that man's muscular work plays an important part in the development of the brain.

Physical exercise (kinesitherapy) is one of the methods used to restore a patient's health as quickly as possible.



## *Respiratory System.* *Respiration*

### GENERAL INFORMATION

There is a continuous interchange of gases between the organism and the external environment. Man, and all higher animals, have special apparatus for this purpose, a system of respiratory organs. The organs of the respiratory system include the nasal cavity, larynx, trachea, bronchi and lungs (Fig. 61). The respiratory organs may be divided, according to their function, into the air passages and the respiratory part. The pulmonary alveoli constitute the respiratory part. Gases between the air and the blood are exchanged in these alveoli. All the other respiratory organs are air passages through which the inhaled and exhaled air passes.

The pharynx is also one of the air passages because during respiration air passes through its nasal and oral parts from the nasal cavity into the larynx.

One of the structural characteristics of respiratory organs is that the walls of most of them have a bony or cartilaginous skeleton and therefore do not collapse; that is why they always contain air. All air passages are lined with mucous membrane which has ciliated epithelium. In the mucous membrane there are glands which secrete mucus onto its surface, and the dust and microbes brought in with the air adhere to the mucus. The cilia of the ciliated epithelium continuously vibrate in the direction opposite to the inhaled air and thus help to keep the air passages clean from dust and microbes. The walls of the pulmonary alveoli have a different structure (see "Lungs").

In studying the respiratory system it should be remembered that it is also associated with other functions, olfaction and sound pro-

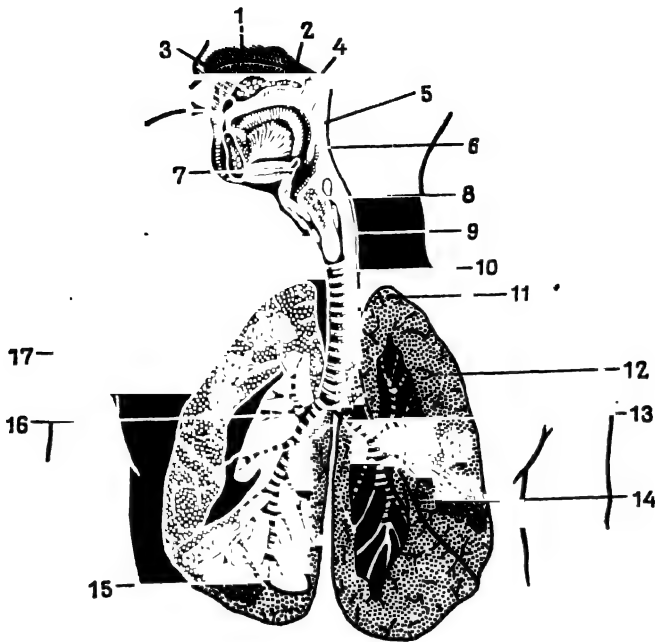


Fig. 61. Respiratory system (diagram)

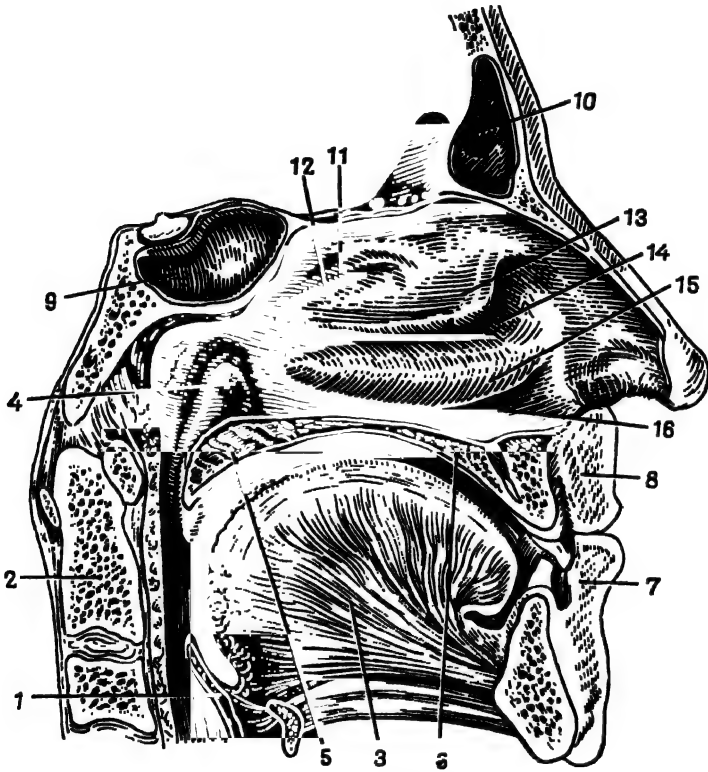
1—nasal cavity; 2—oral cavity; 3—hard palate; 4—nasopharynx; 5—oral part of pharynx; 6—epiglottis; 7—hyoid bone; 8—larynx; 9—oesophagus; 10—trachea; 11—apex of left lung; 12—left lung; 13—bronchus; 14 and 15—pulmonary alveoli, enlarged; 16—bronchus; 17—right lung. Arborization of bronchi in lungs (bronchial tree) are shown

duction. The organ of olfaction is in the nasal cavity; by means of this organ man perceives odours. The organ of sound production is the larynx.

### NASAL CAVITY

The nasal cavity (cavum nasi) is the first part of the respiratory system (Fig. 62). Air enters the nasal cavity through two orifices, the nostrils. The skeleton of the nasal cavity is formed by bones and cartilages. Superior, inferior and two lateral walls, and a septum are distinguished in the nasal cavity. Above the nasal cavity is the anterior cranial fossa, below it is the oral cavity, laterally are the orbits and maxillary sinuses, and posteriorly is the nasopharynx (the bone walls of the nasal cavity are described on pages 78-9). The largest cartilages in the walls of the nasal cavity are the major alar cartilage (paired) and the septal cartilage of the nose. The nasal sep-

tum divides the nasal cavity into right and left halves. Three nasal conchae are suspended from the lateral wall in each half of the nasal cavity; between the nasal conchae are three nasal passages—superior, middle and inferior. The walls of the nasal cavity are lined with a mucous membrane covered with ciliated epithelium. The mucous membrane is relatively thick and very easily swells under the influ-



**Fig. 62. Oral and nasal cavities (section)**

1—epiglottis; 2—second cervical vertebra; 3—tongue; 4—pharyngeal opening of auditory tube; 5—soft palate; 6—hard palate; 7—lower lip; 8—upper lip; 9—sphenoidal sinus; 10—frontal sinus; 11—superior concha; 12—superior nasal passage; 13—middle concha; 14—middle nasal passage; 15—inferior concha; 16—inferior nasal passage

ence of various stimuli (chemical substances, infection, etc.). This membrane contains many blood vessels and nerve fibres with their endings. The blood vessels form numerous networks which are particularly well developed in the anterior part of the nasal septum, which is frequently the site of nasal haemorrhages. The glands of the mucous membrane secrete mucus which moistens the walls of

the nasal cavity. On the surface of the mucous membrane there are always blood cells called leucocytes, which are capable of engulfing microbes. The mucous membrane of the upper part of the nasal cavity contains sensory olfactory cells which constitute the organ of olfaction. The nasal cavity communicates with the nasal accessory sinuses (maxillary, frontal, sphenoidal and ethmoidal) whose walls are lined with a mucous membrane extending from the nasal cavity. The nasolacrimal canal opens into the nasal cavity.

In the nasal cavity the air is cleaned of dust, heated and moistened.

The nasal cavity communicates with the nasopharynx by means of two openings called choanae. From the nasopharynx air moves into the oral part of the pharynx and thence into the larynx. The pharynx is described below (see "Digestive System").

Breathing is possible not only through the nose, but also through the mouth. However, in the latter case the air is insufficiently cleansed and is not heated, and morbid changes may occur in the respiratory organs as a result.

Prolonged oral breathing is accompanied by disturbances in physical development (for example, improper development of the thorax).

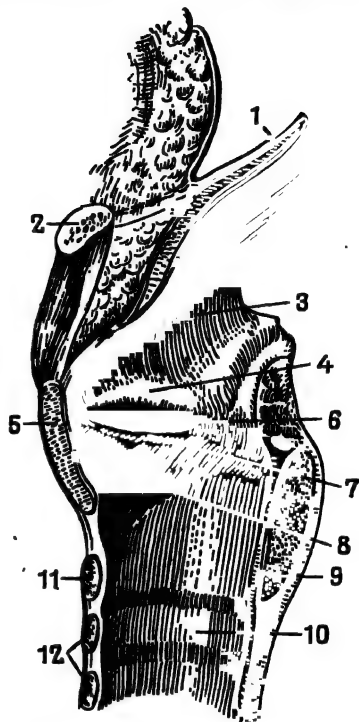


Fig. 63. Larynx (section)

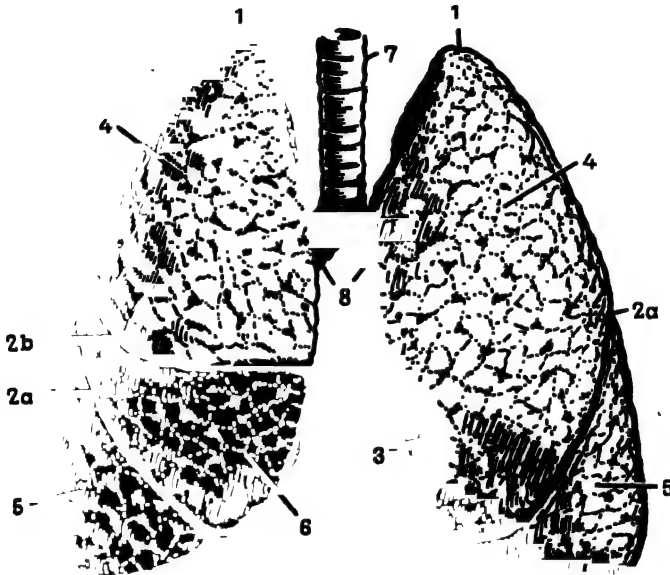
1—epiglottis; 2—hyoid bone; 3, 8 and 10—laryngeal cavity; 4—ventricular fold; 5—thyroid cartilage; 6—laryngeal ventricle; 7—vocal fold; 9—plate of cricoid cartilage; 11—arc of cricoid cartilage; 12—cartilages of trachea

## LARYNX

The larynx is situated in the neck on the level of the fourth to the sixth cervical vertebrae (Fig. 63). Anteriorly it is covered by the muscles of the neck situated below the hyoid bone; laterally it adjoins the lobes of the thyroid gland and large vessels of the neck, and behind it is the pharynx. The skeleton of the larynx is formed of cartilages; the largest of them, the thyroid cartilage, is readily palpated. The smaller cartilages are the cricoid, paired arytenoid and the epig-

lottis. The epiglottis is behind the tongue; during swallowing it covers the entrance to the larynx and keeps food out of the respiratory tract. The cricoid cartilage lies at the base of the larynx. The cartilages articulate by means of ligaments and joints.

The larynx is lined with a mucous membrane covered with ciliated epithelium. On each side of the laryngeal wall there is a recess, called the laryngeal ventricle. Air passes through the larynx which is the



**Fig. 64. Trachea, bronchi and lungs (anterior aspect)**

1—apex of lung; 2a and 2b—interlobar grooves; 3—cardiac notch; 4—superior lobe; 5—inferior lobe; 6—middle lobe (right lung); 7—trachea (windpipe); 8—bronchi

organ of sound production. Sounds are produced by two vocal cords, the right and left vocal cords. They are stretched between the thyroid and arytenoid cartilages, bound the glottis, and consist of fibres of elastic connective tissue. When they are tense, the exhaled air sets them in vibration, and sounds are produced. The tongue, oral cavity, lips and nasal cavity also take part in articulate speech.

The tension or relaxation of the vocal cords and the constriction or dilatation of the glottis depend on contractions of laryngeal muscles. The glottis is dilated by the paired posterior cricoarytenoid muscle. The other laryngeal muscles (lateral cricoarytenoid, cricothyroid, vocalis, etc.) take part in constricting the glottis or in changing the

ension of the vocal cords. All laryngeal muscles are striated (striated).

On the level of the seventh cervical vertebra the larynx merges with the trachea.

### TRACHEA

The windpipe or trachea (Fig. 64) is a tube about 12 centimetres long. The skeleton of the trachea is formed by half-rings of cartilage articulated by ligaments. The posterior wall of the trachea is soft; it consists of a connective tissue membrane and is quite closely connected with the oesophagus. The trachea is lined with a mucous membrane in which there are smooth muscle fibres and glands which secrete mucus. Externally the trachea is covered with a connective tissue membrane.

The trachea enters the thoracic cavity and on the level of the fourth or fifth thoracic vertebrae it divides into two bronchi. This division is called tracheal bifurcation.

### BRONCHI

The right and left bronchi (Fig. 64) are the primary bronchi; they enter the lungs and divide into smaller bronchi. The walls of the bronchi have the same structure as those of the trachea. The right bronchus is wider but shorter than the left one and is continuous with the trachea.

### LUNGS

The lungs (*pulmo* in Latin and *pneumon\** in Greek) are situated in the thoracic cavity (Fig. 64). There are two lungs—right and left. Each lung is conically shaped; the upper part is narrower and is called the apex; the lower part is wider and is known as the base. The apex extends into the neck 2-3 centimetres above the clavicle, and the base is situated above the diaphragm. A lung has three surfaces, costal, diaphragmatic and mediastinal. The mediastinal surface faces the middle and has a recess, called the **gate of the lungs** (hilus pulmonis). This gate gives passage to the bronchi, pulmonary nerves, the pulmonary artery, two pulmonary veins and lymph vessels. All these structures are connected by connective tissue into a common bundle called the **root of the lung** (radix pulmonis).

The primary bronchus, on entering the lung, branches out into smaller bronchi whose walls also contain cartilages. The entire system or arborization of the bronchi in the lung is called the bronchial tree. The smallest bronchi (0.3-0.4 millimetre in diameter) are called

\* Inflammation of the lungs is called pneumonia.

**bronchioles.** Unlike bronchi the bronchioles have no cartilages or glands in their walls, but like the bronchi they are equipped with smooth muscle fibres. Contraction of these fibres may cause spasm (constriction) of the bronchioles.

The right lung consists of three lobes; the left lung has two. The lobes are separated by grooves which may be seen on the surface of



Fig. 65. Bronchioles and pulmonary alveoli of part of pulmonary lobule (magnified 10 times)

1—bronchiole; 2—pulmonary alveoli

the lungs. Each lobe is divided into segments equipped with bronchi of the same size. The right lung has 11 segments (3 in the superior lobe, 2 in the middle lobe and 6 in the inferior lobe), the left lung has 10 segments (4 in the superior lobe and 6 in the inferior lobe). Each segment consists of numerous pulmonary lobules. Between the lobules are layers of connective tissue containing nerves, blood and lymph vessels. The lobule includes a bronchus called a lobular bronchus which divides into bronchioles inside the lobule. The bronchioles expand into alveolar ducts with protrusions on their walls called air vesicles or alveoli (Fig. 65). An alveolus is hemispherical in shape and is 0.2-0.3 millimetre in diameter. The alveolar wall consists of one row of squamous respiratory epithelium, which lies on a thin layer of elastic fibres. The alveoli lie next to a network of vascular capillaries. The interchange of gases takes place through the walls of the alveoli

and the capillaries: oxygen passes into the blood from the alveoli, and carbon dioxide passes into the alveoli from the blood. The alveoli are the respiratory part of the lung; the bronchi are its air-carrying part. There are from 300 million to 400 million alveoli in the lungs of an adult; their total surface area amounts to about 100 square metres.

In structure the lungs resemble a gland of racemose structure.

The lungs are enveloped in a serous membrane\* called the pleura.

### PLEURA

The pleura is a thin lustrous membrane. It envelops each lung, forming two pleural sacs (pulmonary or visceral pleura), and lines the internal surface of the thoracic cavity (parietal pleura).

The parietal pleura consists of three parts—costal, diaphragmatic and mediastinal. Each part of the parietal pleura merges with the next and forms a slit-like space, a sinus, at the site of transition. The most important of these sinuses is the phrenicocostal sinus (right and left). On inhalation the lung dilates and expands into the pleural sinuses except for the lower part of the phrenicocostal sinus.

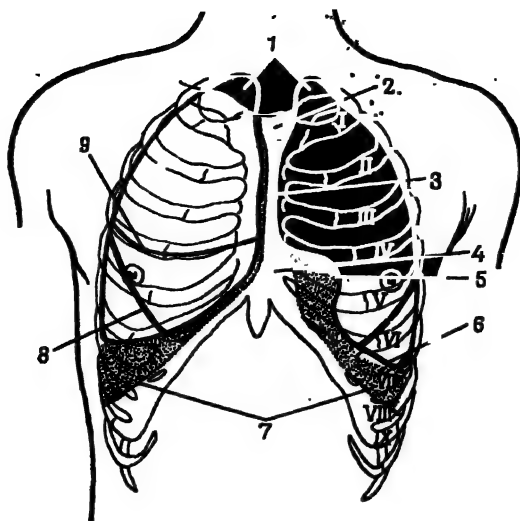
The visceral pleura is fused with the substance of the lung. Both parts of the pleura are joined at the root of the lung. Between the two parts of the pleura there is a slit-like space called the **pleural cavity**. This cavity contains a small amount of serous fluid which moistens the touching parts of the pleura and reduces friction during respiration. The pleural cavity has no air in it and the pressure inside it is negative. The right and left pleural cavities are not connected.

Inflammation of the pleura is called *pleurisy*.

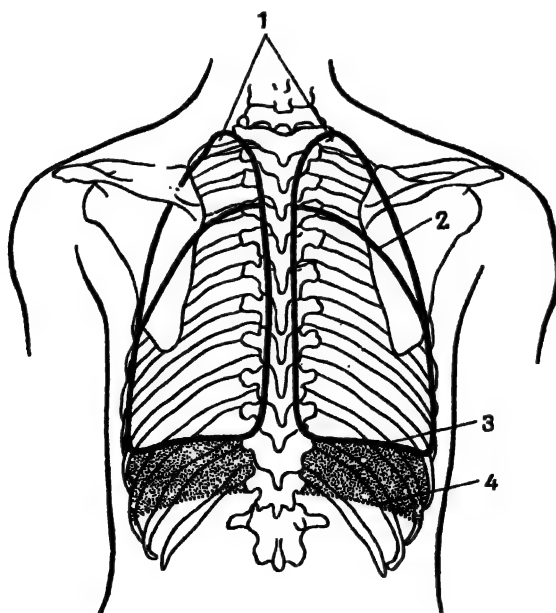
**Borders of the lung and pleura** (Figs. 66 and 67). It is often necessary, in cases of disease of the thoracic organs, to determine the borders of the lungs and the pleura. The apices of the lungs, as mentioned above, are situated in the neck, 2-3 centimetres above the clavicle. The anterior border of a lung is drawn from the apex obliquely downward and inward through the sternoclavicular joint to the articulation between the manubrium and body of the sternum. The anterior border of the right lung descends almost vertically along the sternum (somewhat to the left of the median line) to the level of the sixth rib where it merges with the inferior border. The anterior border of the left lung descends along the sternum only to the level of the fourth rib cartilage where it deviates to the left, crosses the fifth rib cartilage and reaches the sixth rib where it merges with the inferior

\* Serous—from the Latin word serosus meaning serum; the serous membrane secretes a serum-like fluid.





**Fig. 66. Borders of lungs and parietal pleura (anterior aspect)**  
*I-IX—ribs; 1—apices of lungs; 2 and 4—interpleural spaces; 3—anterior border of left lung; 5—cardiac notch; 6—inferior border of left lung; 7—inferior border of pleura; 8 and 9—interlobar grooves*



**Fig. 67. Borders of lungs and parietal pleura (posterior aspect)**  
*1—apices of lungs; 2—interlobar groove; 3—inferior border of lung; 4—inferior border of pleura*

border. This difference between the anterior borders of the right and left lungs is due to the fact that the greater part of the heart is situated left of the median line.

To determine the inferior border of the lung and pleura, the following vertical lines are conventionally drawn: midclavicular (through the middle of the clavicle), midaxillary (through the middle of the axilla), scapular (through the inferior angle of the scapula) and paravertebral (laterally to the vertebral column).

The inferior border of the lung is determined along the midclavicular line on the level of the sixth rib, along the midaxillary line on the level of the eighth rib, along the scapular line on the level of the tenth rib, and along the paravertebral line on the level of the eleventh rib. The inferior border of the pleura runs one rib lower than the border of the lung. The posterior border of the lung is determined along the paravertebral line. The anterior and posterior borders of the pleura almost coincide with those of the lung.

### MEDIASTINUM

The mediastinum is the space occupied by the organs in the thoracic cavity between the two lungs. It is bounded anteriorly by the sternum, posteriorly by the thoracic part of the vertebral column, inferiorly by the tendinous centre of the diaphragm, and laterally by the mediastinal parts of the pleura. The mediastinum is conventionally divided into anterior and posterior parts, the boundary between them running through the roots of the lungs. The anterior mediastinum contains the heart, thymus, and large blood vessels; ascending aorta, pulmonary trunk, superior vena cava, etc. The posterior mediastinum contains the oesophagus, nerves and blood vessels: vagi, sympathetic nerves, thoracic aorta, thoracic lymph duct, etc. The organs of the mediastinum are separated by cellular tissue.

### ROLE OF RESPIRATION

The organism requires not only nutrients, but also oxygen. In the process of metabolism the tissues continuously consume oxygen and produce carbon dioxide. Lack of oxygen kills the tissues and the organism. Nervous tissue is the most sensitive to oxygen deficiency.

The exchange of gases in the tissues, i.e., the consumption of oxygen by the cells and intercellular substance and the liberation of carbon dioxide, is known as **tissue respiration**. Tissue respiration is a complex process requiring the participation of special substances called *respiratory pigments* and *respiratory enzymes*.

The blood delivers oxygen to the tissues and removes the carbon dioxide formed in the process of metabolism. Since oxygen is contin-

uously consumed and carbon dioxide is accumulated, the gases can be maintained at a constant concentration in the blood only if the oxygen is continuously replenished and the carbon dioxide is removed. This process continuously operates in the lungs (pulmonary alveoli) and is called **pulmonary respiration**, i.e., the blood receives oxygen from the pulmonary alveoli and gives off carbon dioxide to the alveoli.

Pulmonary respiration is possible only if fresh air is continuously brought into the lungs from the surrounding atmosphere and the air in the alveoli is removed. This process is called **pulmonary ventilation**.

### *Composition of Inspired and Expired Air*

The atmospheric air entering the lungs during inhalation is called **inspired air**. The air passing out through the air passages during exhalation is called **expired air**. The exhaled air is a mixture of the air which filled the alveoli, the **alveolar air**, and the air which was in the air passages (in the nasal cavity, the larynx, trachea and bronchi). The composition of the inhaled, exhaled and alveolar air is normally constant in a healthy person and is determined by the figures given in Table 1.

These figures may somewhat vary under different conditions (at rest or at work, etc.), but under all conditions the alveolar air differs from the inspired air in that it contains much less oxygen and more carbon dioxide. This is due to the fact that the pulmonary alveoli give off the oxygen of the air to the blood and receive carbon dioxide from the blood.

*Table 1*

**Content of Gases (in %)**

	Oxygen	Carbon dioxide	Nitrogen and other gases
Inspired air . . . . .	20.94	0.03	79.03
Expired air . . . . .	16.3	4	79.7
Alveolar air . . . . .	14.2	5.2	80.6

*The gaseous interchange in the lungs depends on the difference between the oxygen and carbon dioxide pressures in the pulmonary alveoli and the venous blood flowing to the lungs.* The oxygen pressure in the alveoli is higher than in the blood, while the carbon dioxide pressure in the blood is higher than in the alveoli. That is why in the lungs oxygen passes from the air into the blood while carbon dioxide passes from the blood into the air. This transition of gases is governed by

definite physical laws; if the pressure of a gas in a liquid differs from that of the gas in the surrounding air, the gas passes from the liquid into the air or vice versa until the pressures are equalized.

In a mixture of gases, such as air, the pressure of each gas is determined by its percentage content and is called its **partial pressure**. For example, atmospheric air produces a pressure of 760 mm Hg. Air contains 20.94 per cent oxygen, and so the partial oxygen pressure in atmospheric air is 20.94 per cent of the total air pressure, i.e., 159 mm Hg. It has been established that the partial oxygen pressure is 100-110 mm Hg in the alveolar air and 40 mm Hg in the venous blood and pulmonary capillaries. The partial pressure of carbon dioxide is 40 mm Hg in the alveoli and 47 mm Hg in the blood. The difference between the partial pressures of the gases in the blood and in the air determines the gaseous interchange in the lungs. The process is also affected by the cells of the walls of the pulmonary alveoli and of the blood capillaries of the lungs through which the interchange of gases takes place.

### *Transportation of Gases by the Blood*

The blood continuously transports oxygen from the lungs to the tissues and carbon dioxide from the tissues to the lungs. The arterial blood flowing from the lungs contains much more oxygen than it should according to the physical laws governing the solution of gases in liquids. The greater part of the oxygen in the blood is in the form of an unstable chemical compound called oxyhaemoglobin. The oxygen dissolved in the plasma of the blood flowing through the lungs combines with the haemoglobin of the erythrocytes and forms oxyhaemoglobin. Oxygen will keep on dissolving in the blood until all the haemoglobin has changed to oxyhaemoglobin. When atmospheric air is respired under ordinary conditions 96 per cent of the haemoglobin changes to oxyhaemoglobin with the result that the erythrocytes contain 60 times as much oxygen as the blood plasma. This ensures that the tissues receive the amount of oxygen they require for gaseous interchange.

The gaseous interchange in the tissues is governed by the same principle as in the lungs. Oxygen passes from the region of high partial pressure (blood plasma) to the region of low partial pressure (tissue fluid). As oxygen leaves the plasma, the oxyhaemoglobin changes back to haemoglobin thereby ensuring an adequate concentration of oxygen in the plasma.

Carbon dioxide forming in the cells during metabolism passes into the tissue fluid and establishes a high partial pressure there. The partial carbon dioxide pressure is much lower in the blood flowing through the blood capillaries of the organs, and so carbon dioxide passes

from the tissue fluid into the blood. The blood contains much more carbon dioxide than is possible as a result of its solution in the fluid. The carbon dioxide is not only dissolved in the plasma, but also enters into chemical combination with the haemoglobin of the erythrocytes and the plasma salts. This enables all the carbon dioxide formed in the tissues to be carried away. Blood that has released its oxygen and is saturated with carbon dioxide is called venous blood. Venous blood flows to the lungs where pulmonary respiration takes place.

### *Mechanism of Inhalation and Exhalation*

Respiration consists of rhythmically repeated inhalations and exhalations.

**Inhalation** takes place as follows: the muscles participating in inhalation—the diaphragm, external intercostals, etc.—contract under the influence of nerve impulses. When the diaphragm contracts it descends (flattens), increasing the vertical size of the thoracic cavity. Contraction of the external intercostal and certain other muscles elevates the ribs thereby increasing the anteroposterior and transverse size of the thoracic cavity. Thus muscular contraction increases the capacity of the thorax. Since the pleural cavity contains no air and the pressure in it is negative the lungs expand simultaneously with the increase in capacity of the thorax. As the lungs expand the air pressure in them drops (it falls below atmospheric pressure), and atmospheric air rushes into the lungs through the air passages. Hence an inhalation involves a contraction of the muscles, an increase in the capacity of the thorax, an expansion of the lungs with a drop in the pressure inside them, and entrance of atmospheric air into the lungs through the air passages.

Inhalation is followed by **exhalation**. The muscles participating in inhalation relax (the diaphragm rises). The ribs drop as a result of contraction of the internal intercostal and other muscles and because of their own weight. The capacity of the thorax decreases, the lungs become compressed, the pressure in them rises (becomes higher than the atmospheric) and the air rushes out through the air passages.

The respiratory movements are rhythmic. An adult at rest makes 16-20 respiratory movements per minute, children make more movements (a newborn child makes close to 60 movements a minute). Physical exertion, particularly in untrained people, is usually accompanied by faster respiration. Accelerated respiration is also observed in many diseases. Faster respiration may be shallower. Sleep is accompanied by a slowing of respiration.

There are two types of normal respiration: abdominal (predominates in males) and costal (mainly in females). In the former case the capacity of the thoracic cavity increases mainly as a result of con-

traction of the diaphragm (increase in the vertical size), in the latter case it increases as a result of contraction of the other respiratory muscles (increase in the anteroposterior and transverse sizes of the thorax).

### *Vital Capacity of the Lungs*

The vital capacity of the lungs is measured to determine their functional characteristics. The vital capacity of the lungs is the volume of air that can be expelled by the most forcible exhalation after the deepest inhalation. It averages 3,500 cubical centimetres (cc). The vital capacity of the lungs in large measure depends on training, age and sex.

Systematic physical training and sports favour an increase in the vital capacity of the lungs (in some athletes it reaches 6,000-7,000 cc). The vital capacity of the lungs in females is lower than in males; in young people it is higher than in elderly people. The instrument for measuring the vital capacity of the lungs is called a *spirometer* (Fig. 68).

During ordinary respiration the volume of air taken into the lungs in one inhalation is 500 cc. This volume is called **tidal air**. The volume of air that can be inhaled during a maximum inhalation after an ordinary exhalation averages 1,500 cc more than during an ordinary inhalation. This volume of air is called **complemental air**. The air which can be exhaled by a forced exhalation after a normal inhalation averages 1,500 cc more than during an ordinary exhalation and is called **reserve or supplemental air**. The three volumes of air—tidal, complemental and reserve or supplemental—together constitute the respiratory capacity and average  $500 \text{ cc} + 1,500 \text{ cc} + 1,500 \text{ cc} = 3,500 \text{ cc}$  of air.

About 1,000 cc of air remain in the lungs after even the most complete exhalation; this is called the **residual air**.

The presence of residual air means that a lung immersed in water does not sink. The foetus

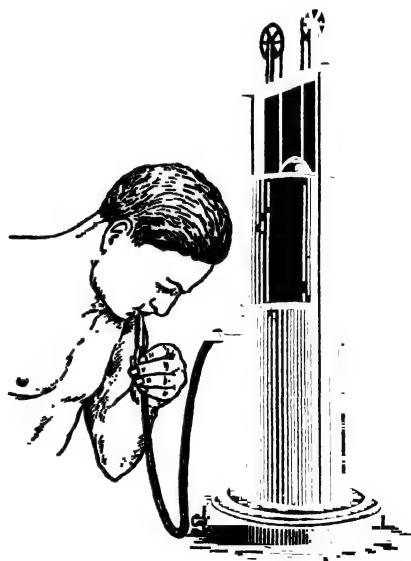


Fig. 68. Spirometry (subject making forcible exhalation)

has no pulmonary respiration before birth, and its lungs contain no air; such lungs do sink. Air enters the lungs after birth with the first inhalation.

**Pneumothorax.** If the thorax is injured and the pleura damaged, atmospheric air enters the pleural cavity; this condition is known as pneumothorax. In this condition the pressure in the pleural cavity is the same as in the lung. As a result of its elasticity the lung collapses and does not participate in respiration. In medical practice air is sometimes introduced into the pleural cavity intentionally (artificial pneumothorax).

### *Regulation of Respiration*

The mechanism of regulation of respiration is very complex. Schematically it is as follows. In the medulla oblongata there is an accumulation of nerve cells which regulate respiration. This is the respiratory centre (its existence was demonstrated by the Russian scientist N. Mislavsky in 1885). In the respiratory centre excitation and inhibition continuously alternate. When it is in a state of excitation it transmits impulses to the spinal cord and thence along nerves to the respiratory muscles with the result that these muscles contract and an inhalation takes place. When the respiratory centre is in a state of inhibition the transmission of impulses to the respiratory muscles ceases, the muscles relax and an exhalation results.

The specific stimulus of the respiratory centre is carbon dioxide. As soon as the blood, which bathes the respiratory centre and the special receptors imbedded in the walls of the blood vessels, accumulates a certain amount of carbon dioxide, the respiratory centre becomes excited and an inhalation takes place. During inhalation the lungs expand, which stimulates the endings of the vagus nerve imbedded in the tissue of the lungs. The excitation arising in the receptors is transmitted along the vagus nerve to the respiratory centre and inhibits it, with the result that an exhalation occurs. During exhalation the surplus carbon dioxide is eliminated from the organism and its concentration in the blood decreases. The next inhalation will take place when the concentration of carbon dioxide in the blood is again sufficient to stimulate the respiratory centre.

Thus respiration is automatically regulated; an inhalation stimulates an exhalation, and the exhalation brings about an accumulation of carbon dioxide which stimulates an inhalation.

If, as a result of intense muscular work, or for some other reason, an excess of carbon dioxide accumulates in the blood, the respiratory centre will be excited immediately after the end of the exhalation because the concentration of carbon dioxide in the blood is already sufficient to excite the centre without further accumulation. In such

cases respiration becomes accelerated, i.e., dyspnoea (difficult or laboured breathing) develops. The carbon dioxide is quickly eliminated from the organism and its concentration in the blood returns to normal. The respiratory rate also becomes normal. The accumulation of carbon dioxide automatically causes it to be eliminated quickly and thereby reduces the excitation of the respiratory centre.

Excitation of the respiratory centre is also evoked by an oxygen deficiency and by certain substances, especially certain drugs, which enter the blood.

Respiration is subject to the control of the cerebral cortex; this is demonstrated by the fact that a person can voluntarily hold his breath (for a very short time, admittedly) or alter the rate and depth of respiration. Cortical regulation of respiration is also evident in the acceleration of respiration during emotional states. Protective acts, such as coughing and sneezing, are associated with respiration. These acts are performed reflexly; the centres of the reflexes are situated in the medulla oblongata.

**Coughing** is the response to irritation of the mucous membrane of the larynx, pharynx or bronchi by particles of dust, food, etc., penetrating into these organs. A cough following a deep inhalation expels the air forcefully from the air passages and the irritant in the air passages is also expelled. As the air is expelled it sets the vocal cords in motion with the characteristic coughing sound.

**Sneezing** is the response to irritation of the mucous membrane of the nose; it works on the same principle as coughing.

Coughing and sneezing are protective respiratory reflexes.

### *Respiration Under Various Conditions*

An adult at rest makes 16-20 respiratory movements a minute. A change in conditions affects the activities of all organs including the respiratory organs.

The interchange of gases sharply increases during physical exertion. Work intensifies the metabolism in the muscles, and the consumption of oxygen and elimination of carbon dioxide associated with it. Pulmonary respiration changes reflexly in response to it. In trained people the gaseous interchange in the lungs increases mainly through deeper respiration, while in untrained people it increases through accelerated respiration. However, the blood of untrained people receives less oxygen than the blood of trained people. Prolonged and intensive muscular work leads to an "oxygen debt" because the demand for oxygen exceeds the supply. This condition is sometimes accompanied by intense dyspnoea, tachycardia (excessively rapid heart action) and other unfavourable phenomena. This may be followed by the onset of so-called second wind in which respiratory movements become even and the working capacity increases.



Sharp changes connected with disturbed gaseous interchange are observed in the organism if the atmospheric pressure is reduced or elevated.

A condition known as *mountain sickness* develops at high altitudes (four kilometres above sea level and higher); it is characterized by a fast pulse and respiratory rate, headache, muscular weakness, etc. It is caused by a marked oxygen deficiency in the tissues, the condition called *hypoxia*. It is well known that at higher altitudes atmospheric pressure is lower. As a result the partial oxygen pressure in the pulmonary alveoli decreases and so does the amount of oxygen which passes from the lungs into the blood. As a result, insufficient oxygen is delivered to the tissues, and this is accompanied by various disturbances in the activities of the organism. To avoid this, special oxygen apparatus are used for flying at high altitudes. Inhalation of oxygen increases the oxygen content in the blood.

People working in caissons or under water where the atmospheric pressure is elevated may suffer from the so-called *caisson disease*. This disease is characterized by pains in the joints and muscles, cutaneous itching, dizziness, vomiting and sometimes fainting (severe cases may result in death). As the atmospheric pressure increases, for example when a diver submerges, the pressure of gases in the pulmonary alveoli also increases. The result is that not only oxygen, but also nitrogen, passes from the lungs into the blood.

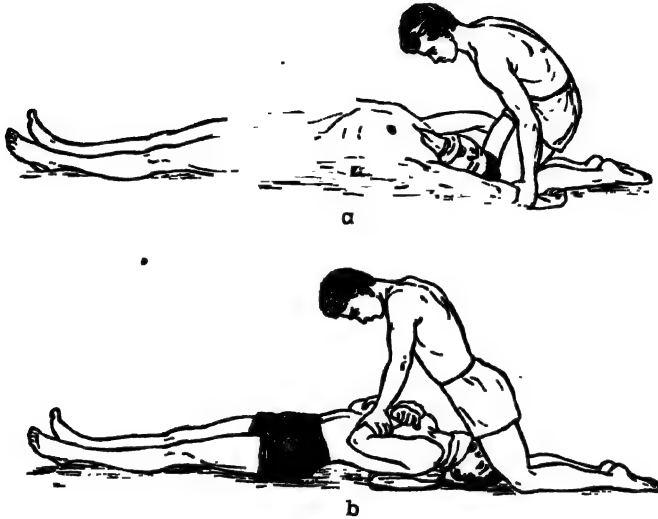
Nitrogen is present in the blood in a dissolved state under normal atmospheric pressure; under elevated atmospheric pressure its concentration increases.

As atmospheric pressure decreases to normal, for example when a diver rises to the surface, the excess of nitrogen passes from the blood into the air. If the pressure drops too rapidly, the nitrogen surplus will not be eliminated from the blood and bubbles of gas will form in the blood vessels. By circulating with the blood these bubbles may cause occlusion of vessels that may be accompanied by various disturbances in the activities of the organism. The transition from elevated pressure to normal atmospheric pressure should be slow in order to prevent caisson disease.

Many diseases are accompanied by laboured breathing, *dyspnoea*. There are different types of dyspnoea, depending on the cause of the respiratory disturbance. Some diseases are characterized by dyspnoea with accelerated and shallow breathing, others by slow and deep breathing, etc. Sometimes dyspnoea is associated with a disturbance in the respiratory rhythm which is usually the result of decreased excitability of the respiratory centre.

### Artificial Respiration

In medical practice it is sometimes necessary to resort to artificial respiration. Artificial respiration is administered in cases of electric shock, drowning, gas poisoning and other instances of respiratory arrest, providing the heart still continues to contract. It is often possible by means of artificial respiration to activate the respiratory centre and to restore normal respiration, thereby saving human lives.



• Fig. 69. Artificial respiration  
a—inhalation; b—exhalation

Several methods of artificial respiration are known. Each method is aimed at alternately increasing and reducing the capacity of the thorax (Fig. 69), so that air enters the lungs and is then expelled from them. The rate at which artificial respiration is administered must coincide with the normal rate of respiratory movements (16 to 20 per minute).

## *Digestive System.*

### *Digestion*

#### GENERAL INFORMATION ..

The digestive system consists of the digestive (or alimentary) tract and digestive glands.

**Digestive tract.** The digestive tract is about 8 to 10 metres long and is divided into the following parts: *oral cavity, pharynx, oesophagus, stomach, small intestine* and *large intestine* (Fig. 70). The structures of the different parts of the tract have common and special features.

The wall of the greater part of the digestive tract consists of *three coats: internal (mucous), middle (muscular), and external (serous)*.

The *internal or mucous coat* is lined with epithelium outside which there is connective tissue with a thin layer of smooth muscle fibres. The mucous coat lodges many blood vessels, and as a result is pink in colour. The numerous small glands imbedded in this coat secrete a viscous mucus which moistens the entire surface of the mucous coat of the digestive tract. It facilitates the movement of food and protects the mucous coat from being damaged by solid particles of food and various chemical substances.

There are also numerous glands in the mucous coat whose secretions contain special substances, called *enzymes*, which take part in the process of digestion (glands of the stomach and small intestine).

The mucous coat of the stomach, oesophagus, and intestines is connected with the muscular coat by means of a *submucous coat* which consists of loose connective tissue. In these parts of the digestive tract the mucous coat forms numerous folds.

In the initial part of the digestive tract there are aggregates of lymphoid tissue, the tonsils, which have a protective function.

The mucous coat of the digestive tract, beginning with the oesophagus, contains lymph nodules which also have a protective function.

The greater part of the *muscular coat* of the digestive tract consists of two layers: an internal layer with *circular muscle fibres*, and an external layer with *longitudinal muscle fibres*. The wall of the pha-

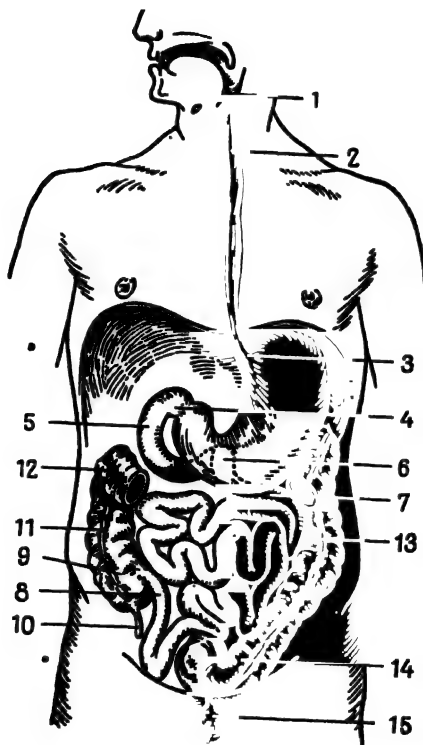


Fig. 70. Diagram of digestive tract

1—pharynx; 2—oesophagus; 3—cardia; 4—stomach merging with duodenum; 5—duodenum; 6—site where duodenum merges with jejunum; 7—jejunum; 8—ileum; 9—caecum; 10—vermiform appendix; 11—ascending colon; 12—site where ascending colon merges with transverse colon (larger part of transverse colon is removed); 13—descending colon; 14—sigmoid colon; 15—rectum

ryn timer and the superior part of the oesophagus, and also the tongue and soft palate, all contain striated muscle tissue. The muscular coat of the other parts of the digestive tract consists of smooth muscle tissue.

Contractions of the muscular coat move food along the digestive tract.

The *serous coat* which covers the digestive organs in the abdominal

cavity is called the *peritoneum*. It is lustrous, whitish and is moistened with serous fluid; it consists of connective tissue lined with monostratal epithelium (*mesothelium*). The pharynx and oesophagus are covered externally not by the peritoneum, but by a layer of connective tissue called the *adventitia*.

**Digestive glands.** The digestive glands secrete digestive juices containing enzymes and other substances which take part in the chemical processing of the food. In addition to the small glands imbedded in the mucous coat of the digestive tract, there are also large glands: the *salivary glands*, the *liver* and the *pancreas*. These glands are situated outside the digestive tract, but communicate with it through ducts.

Every part of the digestive tract and the digestive glands are equipped with nerve fibres and their endings. The walls of many digestive organs (stomach, small intestine, etc.) contain nervous plexus which consist not only of nerve fibres, but also of nerve cells. The endings of sensory nerve fibres perceive various food stimuli—*gustatory*, *thermal*, *mechanical* (for example, pressure of food against the stomach wall), etc. Motor nerve fibres end in the muscular coat of the digestive organs and regulate their contractions; they may cause acceleration or slowing down of *intestinal peristalsis*. The nerves of the digestive glands regulate the secretion of digestive juices (*saliva*, *gastric juice*, etc.).

The nervous system not only regulates the activity of each organ, but also co-ordinates their activities. For example, during swallowing the nervous system ensures co-ordinated contractions of the muscles of the tongue, soft palate, pharynx and oesophagus, so that food passes from the oral cavity into the pharynx and then into the oesophagus and stomach. Saliva, gastric juice and pancreatic juice are secreted when nerve endings in the mucous membrane of the oral cavity are stimulated by food.

#### NUTRIENTS. DIGESTION

The human organism needs a regular supply of food. Food contains nutrients: *proteins*, *carbohydrates*, *fats*, *water*, *mineral salts* and *vitamins*. The nutrients are needed to build up the living substance of the body tissues and are the source of energy used in all vital processes (nervous activity, work of the muscles, contractions of the heart, etc.). The proteins, carbohydrates and fats in food are complex organic substances and cannot be assimilated directly by the organism. They undergo mechanical and chemical treatment in the digestive tract with the result that they are split into simpler water-soluble substances which are absorbed by the blood or lymph and assimilated by the organism. This processing of food in the digestive tract is called *digestion*.

The mechanical treatment of food consists in breaking it up and grinding it. This helps to mix it with the digestive juices (*liquefaction of the food*) and makes the subsequent chemical treatment by enzymes more effective. The food is treated chemically by digestive juices: saliva, bile, gastric, pancreatic, and intestinal juices. All these juices, except bile, contain special substances called enzymes.

**Digestive enzymes** are organic substances which act as catalysts, i.e., they are substances which accelerate chemical reactions. Under the influence of these enzymes the proteins, carbohydrates and fats are split in the digestive tract into simpler, soluble substances. There are several types of digestive enzymes, which have specific action, i.e., each enzyme participates in the splitting of a particular substance. The enzymes of the digestive juices are therefore divided into three groups: (1) *protein-splitting*, (2) *carbohydrate-splitting*, and (3) *fat-splitting*. Their activity is influenced by their environment; for example, the enzymes of gastric juice act only in an acid medium, and those of intestinal juice act only in an alkaline medium. Each digestive juice contains definite enzymes. A small quantity of enzymes influences a large quantity of nutrients because, while the enzymes participate in the digestion of food, they undergo no change and so may enter into further reactions. The splitting of complex organic substances operates very rapidly at a relatively low temperature (body temperature).

We shall now examine the properties of the nutrients and the changes they undergo in the process of digestion.

**Proteins** are the most complex organic substances. They are used in the organism mainly as plastic material, i.e., to build up living substance. In this respect they cannot be replaced by any other substances. Proteins consist of *carbon, hydrogen, oxygen, nitrogen, sulfur* and *phosphorus*. Since they contain nitrogen they are called *nitrogenous substances*. Other organic substances contain no nitrogen. In the process of digestion proteins are split into intermediate products, *peptones* and *albumoses*, which in their turn break down into less complex substances, *amino acids*. Amino acids are soluble in water and can be absorbed and assimilated by the organism.

The proteins of different organisms and of different tissues of the same organism possess specific properties. The properties of food proteins depend on the amino acids of which they are composed. Some proteins contain all the amino acids required by the organism, while others contain only some of them. The former are referred to as adequate proteins, and the latter as inadequate proteins. The most valuable proteins are found in meat, milk and eggs. They contain all the amino acids required by the organism. These proteins are particularly needed by children. Proteins of vegetable origin contain only some of the amino acids necessary for the human organism. The most

valuable of them are the proteins found in beans, potatoes and some other plants. Food must contain various proteins, including those of vegetable origin.

**Carbohydrates** or **saccharides** are the source of energy in the organism and constitute part of the tissues. They consist of carbon, hydrogen and oxygen, the latter two being present in the same ratio as in water (hence the term *carbohydrate*—carbon combined with water). Three groups of carbohydrates are distinguished according to the complexity of their chemical structure; *monosaccharides*, *disaccharides* and *polysaccharides*\*. Grape sugar, or *glucose* and *fructose* (sugar contained in fruit) are examples of monosaccharides. Disaccharides consist of two monosaccharide molecules. *Cane sugar* is a disaccharide. Polysaccharides have a more complex structure. They include *starch*, *glycogen*, etc. In the process of digestion complex carbohydrates are split into monosaccharides which readily dissolve and are easily absorbed and assimilated by the organism. A good deal of carbohydrates is present in foods of vegetable origin (bread, vegetables, fruit).

**Fats** are a rich source of energy and are a constituent of all tissues. They consist of the same elements as carbohydrates, but in different proportions. During the process of digestion fats are split into *glycerin* and *fatty acids*, the latter entering into a chemical reaction with the alkalis present in the small intestine and forming soaps which readily dissolve and are easily absorbed. The properties of the different fats depend on the fatty acids of which they are composed. There are three basic fatty acids: *oleic*, *palmitic* and *stearic*. Vegetable oil is an example of a fat containing oleic acid; palmitic acid is a constituent of butter; stearic acid is present in solid fats (lard, etc.). The human organism needs all types of fatty acids, and the food must therefore contain fats of both animal and vegetable origin.

Other constituents of the tissues are the so-called *fatlike substances* (*lipids*). In addition to carbon, hydrogen and oxygen these substances contain phosphorus and other elements. Among the lipids are *lecithin* and *cholesterol*. Large amounts of fatlike substances are present in nervous tissue, blood and bone marrow. Vitamin D, the adrenocortical hormone and the sex hormones (see "Endocrine Glands") are similar to cholesterol in composition. Relatively large amounts of lipids are found in egg yolk, milk and roe.

**Water and mineral salts** form part of all tissues of the organism; however, they are not sources of energy. The amount of water in the adult human body may reach 70 per cent of its total weight.

The organism receives water both in food and drink. Vegetables

\* The prefixes *mono* (one), *di* (two) and *poly* (many) indicate the number of molecules of which the carbohydrates are composed.

and fruit contain a particularly large amount of water, although all foodstuffs also contain a certain amount of water. In the process of digestion water is the solvent of all substances assimilated by the organism. Water is absorbed into the blood in the small and large intestines.

The mineral salts present in the organism in the greatest amounts are those of calcium and phosphorus, while there are smaller amounts of the salts of *chlorine, iron, iodine, sodium, potassium*, etc. The daily requirement of most of these salts is small and amounts to grams for some of them (calcium), milligrams for others (iron), and even parts of a milligram for still others (the so-called trace elements, for example, cobalt). The normal variety of food usually gives the organism all the mineral salts it needs, except for common salt (NaCl) which has to be added to the food.

Vitamins are special organic compounds in food. They are not sources of energy, but they affect metabolism and other processes in the organism. A varied diet will provide enough vitamins. Vitamin deficiency is accompanied by various disturbances.

Water, mineral salts and vitamins are utilized by the organism in the state in which they are ingested with the food.

Nutrients are usually ingested not in their pure state, but as constituents of mixed food. Most foodstuffs (meat, bread, milk, etc.) contain all the nutrients, although in varying amounts.

## ORAL CAVITY

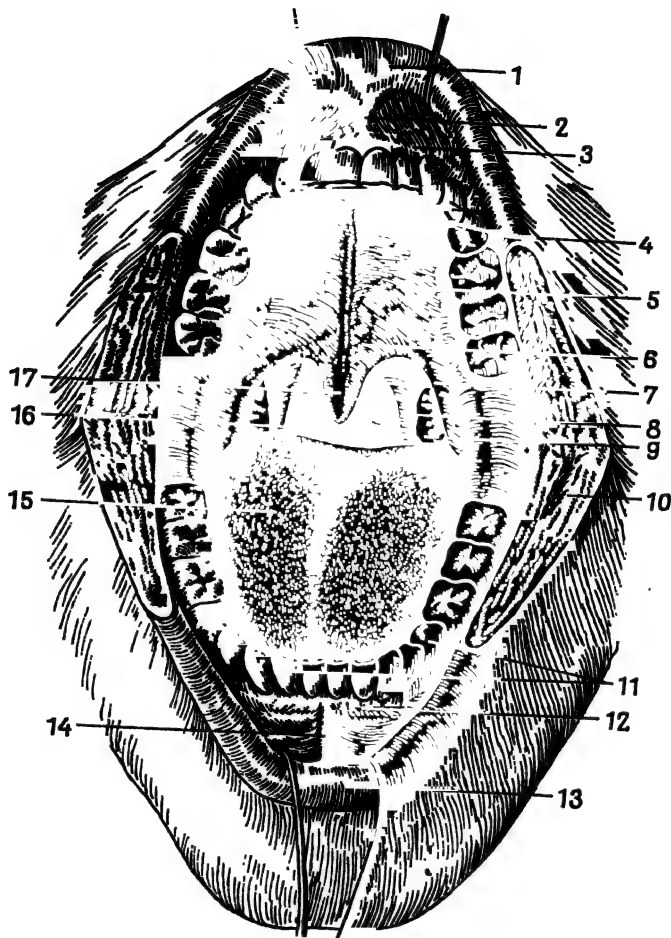
The *oral cavity (cavum oris)* is the initial enlarged part of the digestive tract (Fig. 71). It consists of the vestibule and the oral cavity proper.

The *vestibule of the mouth* is a slitlike space bounded externally by the lips and cheeks, and internally by the teeth and alveolar processes of the jaws. The lips and cheeks contain the mimetic muscles; they are covered externally with skin, and are lined (in the vestibule) with a mucous membrane. This mucous membrane extends from the lips and cheeks to the alveolar processes of the jaws and forms in the median line the *frenula* of the upper and lower lips. The mucous membrane on the alveolar processes of the jaws closely adheres to the periosteum and is called the *gum (gingiva)*.

The *oral cavity proper* is bounded superiorly by the *hard and soft palates*, inferiorly by the *oral diaphragm*, and anteriorly and laterally by the *teeth and alveolar processes*; posteriorly it communicates with the pharynx through the *fauces*.

The *hard palate* separates the oral cavity from the nasal cavity; it is made up of the *palatine processes of the maxillae* and the *hori-*





**Fig. 71. Oral cavity (cheeks are sectioned)**

**1—upper lip; 2—frenulum of upper lip; 3—gum; 4—upper teeth; 5—hard palate; 6—soft palate; 7—glossopalatine arch; 8—pharyngopalatine arch; 9—palatine tonsil; 10—section of cheek; 11—lower teeth; 12—gum; 13—lower lip; 14—frenulum of lower lip; 15—tongue (dorsum); 16—fauces; 17—uvula**

*zontal plates of the palatine bones*, and is covered with a mucous membrane.

The *soft palate* is situated to the posterior of the hard palate and is a muscular plate covered with a mucous membrane. The conical part of the soft palate situated along the median line is called the *uvula*. The following muscles are found in the soft palate: the *tensor veli palatini* (tenses the soft palate); the *levator veli palatini* (raises the soft palate), and *uvulae*. These muscles consist of striated muscle tissue.

The *oral diaphragm* or *floor of the oral cavity* is formed by the *mylohyoid muscles*. On the floor of the oral cavity the mucous membrane forms a fold called the *frenulum of the tongue*.

On the sides of the diaphragm there are two eminences. These are the *salivary papillae*, which open the ducts of the submaxillary and sublingual glands.

The *fauces* is the space connecting the oral cavity with the pharynx. It is bounded superiorly by the soft palate, inferiorly by the base of the tongue, and laterally by the palatine arches. There are *two arches*—*glossopalatine* and *pharyngopalatine*—on each side of the fauces. They are folds of mucous membrane which lodge muscles bearing the same names as the arches. These muscles lower the soft palate.

Between the arches is a recess, or *sinus*, which lodges a *palatine tonsil*. Man has a total of *six tonsils*: *two palatine*, *one lingual*, *one pharyngeal*, and *two tubal*. The lingual tonsil is situated in the mucous membrane of the base of the tongue, while the pharyngeal and tubal tonsils are found in the mucous membrane of the pharynx (see below). Each tonsil consists of lymphoid tissue which forms follicles of different sizes. They are the site of reproduction of lymphocytes. The tonsils play a barrier role (protection from harmful microbes).

All the tonsils together form the so-called *lymphatic ring*. The fauces of every patient, especially children, is inspected during each medical examination because of the changes occurring in the fauces in many diseases (*angina*, *scarlet fever*, etc.).

### *Tongue*

The *tongue* (*lingua* or *glossa*) is a muscular organ covered with a mucous membrane (Fig. 72). It consists of a *tip*, a *body* and a *base*. The base of the tongue is fastened to the hyoid bone, while the body and tip are free. The superior surface of the tongue is called the *dorsum*.

The muscles of the tongue are divided into lingual muscles proper and muscles with their origins on bones. The lingual muscles proper consist of *muscle fibres* running in three directions—longitudinal,

transverse and vertical; contraction of these muscles alters the shape of the tongue. Three pairs of tongue muscles, the *hyoglossus*, *genioglossus* and *styloglossus* muscles, have their origins on bones. All of them end in the tongue. These muscles move the tongue forward, backward, up and down.

The mucous membrane on the dorsum of the tongue forms numerous nipple-like eminences, called *papillae*. There are *four types of papil-*

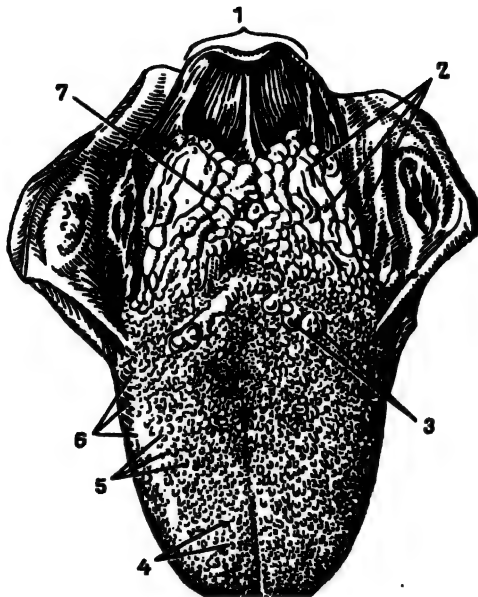


Fig. 72. Tongue (dorsum)

1—epiglottis; 2—lingual tonsil; 3—vallate papillae; 4—filiform papillae; 5—fungiform papillae; 6—foliate papillae; 7—base of tongue

*lae: filiform, fungiform, vallate and foliate.* The filiform papillae possess tactile sensitivity (perceive touch). All the other papillae are gustatory. The papillae give the tongue its velvety appearance. In many diseases (for example, gastro-intestinal) the external appearance of the mucous membrane of the tongue changes, and this is taken into consideration in making a diagnosis.

There is an accumulation of lymphatic tissue in the mucous membrane of the base of the tongue; this is the lingual tonsil.

*Functions of the tongue.* The tongue is the organ of taste. It also possesses thermal, pain and tactile sensitivity. It helps to mix the

food during mastication and to push it during swallowing. In man the tongue also participates in articulate speech.

### Teeth

The *teeth (dentes)* in the oral cavity are fastened in the sockets (alveoli) of the alveolar processes of the jaws. A tooth consists of three parts: a *crown*, a *neck* and a *root* (Fig. 73). The crown of the tooth extends into the oral cavity, while the root is fastened in an alveolus. The neck is the constricted part at the line of junction between the crown and the root; it is covered by the gum. Inside the tooth there is a cavity which extends to the *root canal*. The cavity of the tooth is occupied by *dental pulp* formed by loose connective tissue which contains blood vessels and nerves.

The tooth is formed of three substances—*dentin*, *enamel* and *cementum*. *Dentin* is considered the main substance because it constitutes the greater part of the tooth. It somewhat resembles bone in structure, but is stronger. *Enamel* covers the crown of the tooth; it is the hardest tissue in the human body, containing 98.5 per cent inorganic salts. *Cementum* covers the root and neck of the tooth; its structure resembles bone even more closely than that of dentin.

Between the root of the tooth and the wall of the socket in the alveolar process there is a small layer of connective tissue called the *pericementum*. The collagenous fibres of the pericementum form a ligament which reinforces the tooth.

The teeth are divided, according to their shape, into *incisors*, *canines*, *molars* and *premolars*. The crown of the incisors is chisel-shaped, while that of the canines is conical. The crown of the premolars has two cusps, and that of the molars has four or five cusps. The incisors and canines are intended for biting food, and the molars and

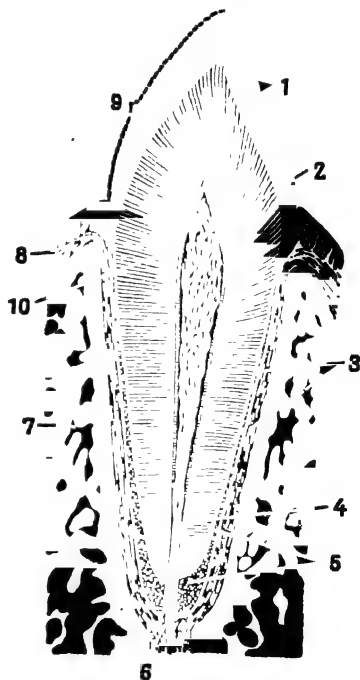


Fig. 73. Tooth (section)

1—enamel; 2—cavity filled with pulp; 3—pericementum; 4—root canal; 5—cement; 6—opening at apex of tooth giving passage to nerves and vessels; 7—bone substance of jaw; 8—gum; 9—crown; 10—dentin

premolars for grinding it. The different kinds of teeth have different numbers of roots; the incisors and canines have one root, the premolars have one and sometimes two, the inferior molars have two and the superior molars three roots each. In man teeth erupt twice; the first set are called the *milk teeth*, and the second are the *permanent teeth*.

*There are 20 milk teeth*—5 in each half of the upper and lower sets (2 incisors, 1 canine and 2 molars). The milk teeth come through at the age of 6 months to 2-2.5 years in the following sequence: first the middle incisors, then the lateral incisors, first molars, canines, and finally the second molars. The timeliness of dentition is one of the signs of a child's normal development. In some diseases (for example, rickets) the dentition is delayed.

*There are 32 permanent teeth*. The number of teeth is usually given by the dental formula which for the permanent teeth is as follows:

$$\frac{2.1.2.3}{2.1.2.3}$$

The formula indicates that in each half of the upper and lower sets there are 2 incisors, 1 canine, 2 premolars and 3 molars. The third molar is called the wisdom tooth.

The permanent teeth appear at the age of 7 to 14 years, except for the wisdom teeth which erupt at the age of 17 to 30 years, and sometimes do not erupt at all. The first molars are the first of the permanent teeth to appear (in the 7th year of life). The permanent teeth appear in the following order: first molars, middle incisors, lateral incisors, first premolars, canines, second premolars, second molars and, lastly, the wisdom teeth.

### Salivary Glands

Numerous small glands (*labial, buccal, palatine and lingual*) whose secretion contains mucus are imbedded in the mucous membrane of the oral cavity. Moreover, there are three pairs of large salivary glands, the *parotid, submaxillary* and *sublingual glands*, whose ducts also open into the oral cavity (Fig. 74).

The *parotid gland (glandula parotis)* is situated below and in front of the external acoustic meatus. The duct of this gland runs along the external surface of the masseter muscle, pierces the buccinator muscle and opens in the vestibule of the mouth on the mucous membrane of the cheek.

The *submaxillary gland* is situated under the oral diaphragm in the submaxillary fossa. The duct of this gland lies on the superior surface of the oral diaphragm and opens into the oral cavity proper on the salivary papilla under the tongue.

The *sublingual gland* is situated under the tongue on the oral diaphragm; it is covered superiorly with a mucous membrane which forms the *sublingual fold* under the gland. The gland has one large and several small ducts. The large duct opens together with the duct

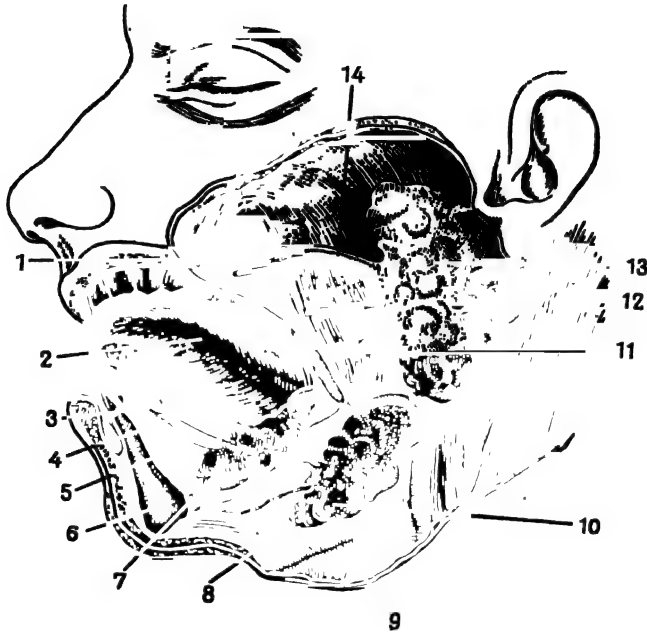


Fig. 74. Salivary glands

1—buccinator muscle; 2—tongue; 3—salivary papilla; 4—duct of submaxillary gland; 5—duct of sublingual gland; 6—lower jaw; 7—sublingual gland; 8—mylohyoid muscle; 9—hyoid bone; 10—submaxillary gland; 11—masseter muscle; 12—sternocleidomastoid muscle; 13—parotid gland; 14—duct of parotid gland

of the submaxillary gland on the salivary papilla, while the small ducts open on the *sublingual fold*.

The secretion of the salivary glands is called *saliva*.

#### DIGESTION IN THE ORAL CAVITY

The gustatory properties of food, its temperature and consistency are determined in the oral cavity where the process of digestion begins and the food undergoes mechanical and chemical processing.

The mechanical processing consists in the fact that the food is broken up and ground by the teeth during mastication. At the same time it is mixed and moistened with saliva and forms a bolus. The

chemical processing is carried out by the enzymes contained in the saliva and acting on the food.

**Composition and action of saliva.** The saliva is a clear alkaline fluid. It contains 98.5-99 per cent water and 1-1.5 per cent organic and inorganic substances. Saliva contains *mucin*, which is a viscous mucous substance, and two enzymes—*ptialin* and *maltase*. The mucin envelops the food in the oral cavity and forms a bolus which is easy to swallow. The enzymes of the saliva exert chemical action on starch and help to transform it into simple sugar.

This action continues in the stomach until the bolus becomes impregnated with the *acid gastric juice*. The saliva contains no enzymes which split fats and proteins.

In the course of a day a man secretes up to 1.5 litres of saliva. It should be remembered that not only the amount, but also the composition of saliva varies with the character of the food and its physical and chemical properties. In experiments on dogs it has been established, for example, that much more saliva is secreted for dry food than for liquid food. In man the dryness of food is not so important. The secretion of saliva is greatly increased when the oral cavity is stimulated with acid or water; mastication also helps salivation reflexly (the better the food is masticated, the more saliva is secreted). Dogs salivate only when eating food. Man salivates continuously, even between meals, although only small amounts of saliva are secreted at this time.

**Regulation of salivation.** The activity of the salivary glands was studied by I. Pavlov and his pupils. Pavlov elaborated a method of establishing a permanent (chronic) fistula which enabled him to obtain pure saliva in order to study its quality and quantity. This method involves bringing the opening of the duct of the animal's salivary gland (most commonly the parotid gland) out of the oral cavity to the exterior and suturing it to the skin. Through this opening the saliva is secreted and is collected in a test tube (Fig. 75). Animals with a permanent fistula live for years. To study salivation in man a special metal capsule is used; the capsule is made to adhere to the mucous membrane of the cheek around the opening of the duct of the salivary gland, and is then connected to a rubber tube through which saliva flows to the exterior.

Pavlov's method established that the activity of the salivary glands is regulated reflexly by the nervous system. The food in the oral cavity stimulates the sensory nerve endings, particularly the taste receptors. Along sensory nerves the excitation (nerve impulses) is transmitted to the centre of salivation in the central nervous system, in this case the medulla oblongata. From the centre of salivation nerve impulses run along efferent (secretory) nerves to the salivary glands and cause them to secrete saliva. The unconditioned salivary reflex

is brought about in this way. Saliva may be secreted not only when food is introduced into the mouth, but also, as mentioned above, at the sight and smell of food, and in man even at the mention of it. These are cases of conditioned reflex salivation with the reflex arc coupling in the cerebral cortex.

The secretion of saliva is affected by certain chemicals, for exam-

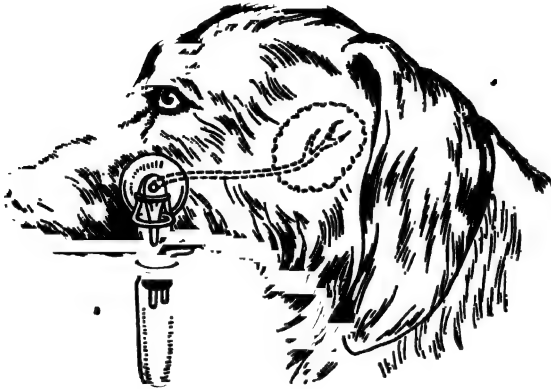


Fig. 75. Dog with fistula of parotid gland. Funnel and test tube to collect saliva are fastened onto cheek at opening of gland duct brought out to exterior

ple, some medicinal substances. Pilocarpine, which is used in certain diseases, may produce copious salivation, whereas atropine may reduce the secretion of the salivary glands.

## DEGLUTITION

As stated above, food is broken up, mixed and moistened with saliva in the oral cavity. When the bolus or liquid food stimulates the receptors of the posterior part of the oral cavity (soft palate, fauces) and then the receptors of the pharynx, nerve impulses are transmitted along sensory nerve fibres to the *centre of deglutition* situated in the medulla oblongata and thence along motor nerve fibres to the muscles participating in deglutition.

Deglutition is a complex act involving the muscles of the tongue, oral floor, soft palate, pharynx and oesophagus. During deglutition the mouth closes, the soft palate rises and separates the nasopharynx from the rest of the pharynx, the larynx and hyoid bone rise, and the tongue moves back and pushes the bolus. The epiglottis closes the entrance to the larynx so that no food can get into the respiratory tract.



Through the fauces the swallowed bolus enters the pharynx, and from there it goes through the oesophagus to the stomach.

The bolus is moved through the pharynx and oesophagus by the contractions of the muscular coat of these organs.

### PHARYNX

The pharynx serves to transfer the food from the oral cavity to the oesophagus, and to transmit air from the nasal cavity to the la-

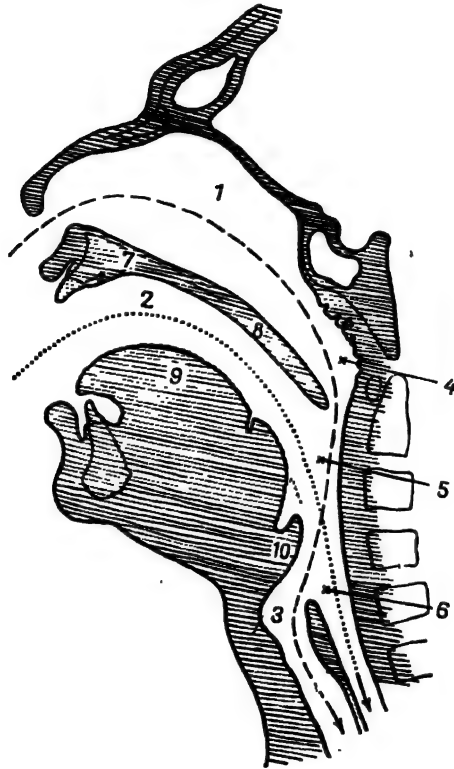


Fig. 76. Diagram showing passage of food (...) and air (— — —)

1—nasal cavity; 2—oral cavity; 3—laryngeal cavity; 4—nasal part of pharynx; 5—oral part of pharynx; 6—laryngeal part of pharynx; 7—hard palate; 8—soft palate; 9—tongue; 10—epiglottis

ryn timer (Fig. 76). It is a tube situated at the back of the nasal cavity, oral cavity and larynx, and is therefore divided into *three parts*—*nasal* or *nasopharynx*, *oral* or *oropharynx*, and *laryngeal* or *laryngopharynx*. The upper part of the pharynx is attached to the base of the skull,

while the lower part merges with the oesophagus on the level of the sixth or seventh cervical vertebrae. Behind the pharynx is the cervical part of the vertebral column.

The wall of the pharynx consists of *three coats*—a *mucous coat*, a *muscular coat* and the *adventitia*. The mucous coat contains a large number of mucous glands. The mucous coat of the nasopharynx lodges three tonsils: the pharyngeal tonsil and two tubal tonsils. There are three pairs of muscles in the muscular coat of the pharynx, called the *constrictors of the pharynx* and another two pairs which raise the pharynx, called the *palatopharyngeus* and *stylopharyngeus muscles*.

The nasopharynx communicates with the nasal cavity through two *apertures*, or *choanae*. Each lateral wall of the nasopharynx contains an opening leading to the *auditory (eustachian) tube*. The auditory tube connects the pharynx with the *tympanic cavity of the temporal bone (cavity of the middle ear)*.

### OESOPHAGUS

The oesophagus is a tube about 25 centimetres long (see Fig. 70), through which food passes to the stomach. The initial part of the oesophagus is situated in the neck, the greater part lies in the thoracic cavity in front of the vertebral column next to the thoracic aorta, and about three centimetres of it lie in the abdominal cavity. From the thoracic cavity it extends to the abdominal cavity through the opening in the lumbar part of the diaphragm. There are three constrictions in the oesophagus: one at the beginning, one on the level of the fourth thoracic vertebra, and one where it passes through the diaphragm. Accidentally swallowed foreign bodies may become lodged in the constrictions.

The wall of the oesophagus consists of a mucous coat, a submucous coat, a muscular coat, and the adventitia. The mucous coat has longitudinal folds which straighten out when food passes through the oesophagus. Food is moved through the oesophagus by the contractions of its muscular coat. The adventitia, the external coat of the oesophagus, touches the adjacent organs. The oesophagus merges with the stomach on the level of the eleventh thoracic vertebra.

### STOMACH

The stomach (*gaster*) is the expanded part of the digestive tract (Fig. 77). It serves as the container of food, which is partly digested in it. It is situated in the upper part of the abdominal cavity under the diaphragm, in the left hypochondriac and epigastric regions. The greater part of the stomach (five-sixths) is situated left of the median line, while the rest of it lies right of the median line. The stomach is

made up of the following parts: *oesophageal orifice (cardia)*, *fundus, body, pyloric portion or pylorus*, and *two borders* called the *greater and lesser curvatures*. The size and shape of the stomach vary with the amount of food consumed and the extent of contraction of its wall. The stomach filled with food is usually compared with a chemical retort. Its capacity is one to two litres.

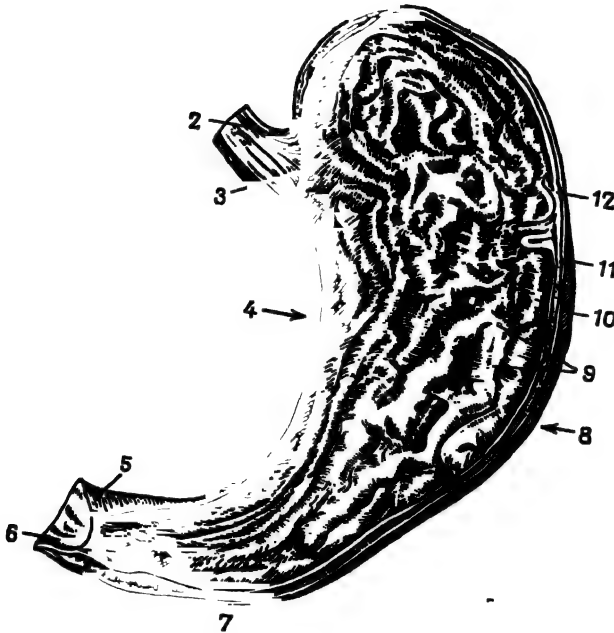


Fig. 77. Stomach (frontal section)

1—fundus ventriculi; 2—oesophagus (abdominal part); 3—cardia; 4—lesser curvature; 5—pyloric sphincter; 6—duodenum (initial); 7—pylorus; 8—greater curvature; 9—folds in mucous coat; 10—serous coat; 11—muscular coat; 12—mucous coat

The *wall of the stomach* consists of four coats—mucous, submucous, muscular and serous (peritoneum).

The *mucous coat* forms numerous folds which straighten out as the stomach fills with food. At the boundary of the stomach and the duodenum there is a circular fold of mucous membrane known as the *pyloric valve*. In addition to the folds the mucous coat also contains permanent small *gastric pits* into which the ducts of the gastric gland open.

The *gastric glands* vary in shape; in an adult the total number is close to 40 million. Glands of the fundus, body, pylorus and cardia

are distinguished according to their location. The glands of the fundus and body consist of three types of cells: chief, parietal and accessory. Other parts of the stomach have no parietal cells. The chief cells produce enzymes, and the parietal cells produce hydrochloric acid. In the wall of the stomach there are glands which secrete mucus. The secretion of all gastric glands is called *gastric juice*.

Unlike the other parts of the digestive tract, the muscular coat of the stomach consists not of two, but of three layers—*circular, longi-*

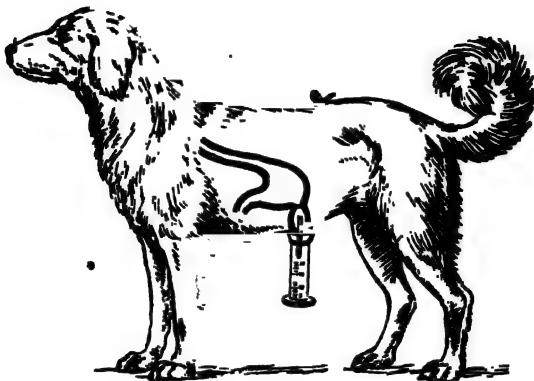


Fig. 78. Dog with isolated pouch

*tudinal* and *oblique*. At the boundary between the stomach and duodenum the circular muscle fibres form a thickening, the *pyloric sphincter*. It is situated in the pyloric valve and periodically contracts and relaxes. When it contracts the stomach and duodenum are divided and no food passes into the duodenum. When it relaxes a portion of the *chyme* passes from the stomach into the duodenum.

The contractions of the muscular coat of the stomach are accompanied by periodic wave-like movements of its walls. These movements proceed from the cardia towards the pylorus and are called *peristalsis*.

The serous coat, the peritoneum, envelops the stomach and extends to other organs, forming folds—the gastrosplenic fold and the great and lesser omenta (see “Peritoneum”).

### DIGESTION IN THE STOMACH

Various observations have been conducted for the purpose of studying the composition and quantity of gastric juice, its action on the food, and the mechanism of juice secretion in the stomach. Pavlov

performed an operation of establishing an isolated stomach (pouch) in dogs; the operation enabled him to obtain pure gastric juice and to study its composition. In this operation a flap is cut out of the wall of the stomach and a pouch is made from the flap (Fig. 78). The incisions on the stomach are made so as to preserve the nerves which innervate the pouch. Dogs operated in such manner live on for years. When such a dog eats, no food passes into the pouch, but gastric juice is secreted in it as in the main portion of the stomach in which the food is digested. Pure gastric juice, without an admixture of food, is brought out to the exterior through a fistula. The secretions in the pouch offer an idea of gastric juice secretion in general. Other experiments have also been conducted to investigate digestion in the stomach (sham feeding, mechanical stimulation of the wall of the stomach, etc.).

The contents of the human stomach are studied by using a stomach tube, which is a special rubber tube of different diameters. Other methods of investigating the functions of the stomach are also used, in particular, examinations by X-rays. The character of gastric digestion has been determined as a result of numerous studies.

Food stays in the stomach from 3 to 8 or 10 hours, depending on its composition; in the stomach it undergoes mechanical and chemical processing. Liquid food passes from the stomach into the small intestine more quickly than solid food. Food rich in protein is retained in the stomach longer than food rich in carbohydrates. Fatty food stays in the stomach the longest.

**Composition and action of gastric juice.** Gastric juice is a clear acid fluid containing *enzymes*, *hydrochloric acid*, *mucin*, and other organic and inorganic substances. The chief enzyme is *pepsin*, but gastric juice also contains the *rennet enzyme (chymosin)* and *lipase*.

*Pepsin* splits proteins into intermediate substances called *peptones* and *albumoses*. It should be remembered that pepsin acts only in an acid medium.

The *rennet enzyme* curdles milk so that it is retained in the stomach for a longer time and is digested. This is particularly important for nurslings.

*Gastric lipase* digests fats, splitting them into fatty acids and glycerin. However, it acts only on emulsified fats, such as the fat contained in milk which is suspended in the form of minute droplets.

*Gastric juice* has no enzymes which split carbohydrates, but *ptyalin*, the enzyme of the saliva, continues to act in the stomach for 30-40 minutes until the bolus becomes impregnated with gastric juice.

*Hydrochloric acid* is an important constituent of gastric juice. It intensifies the activity of the enzymes and, in addition, is bactericidal, i.e., capable of killing bacteria.

Gastric juice contains 0.3-0.5 per cent hydrochloric acid. The for-

mation of this acid requires common salt which man consumes with his food. Some gastric diseases are characterized by increased or decreased hydrochloric acid content in the gastric juice, which affects the activity of pepsin.

The amount and composition of gastric juice vary with the character of the food. Gastric juice secretion was traced in Pavlov's laboratory after the ingestion of bread, meat and milk. Bread contains a great deal of carbohydrates and meat is rich in proteins, while milk is a mixed food. The main changes in the character of gastric juice secretion for different foodstuffs are shown in Table 2.

Table 2

Changes in the Character of Gastric Juice Secretion

Amount of juice	Content of hydrochloric acid	Content of enzymes (especially pepsin)	Duration of salivation
Greatest on ingestion of meat	Greatest on ingestion of meat	Greatest on ingestion of bread	Longest on ingestion of bread
Less on ingestion of bread	Less on ingestion of milk	Less on ingestion of meat	Shorter on ingestion of meat
Least on ingestion of milk	Least on ingestion of bread	Least on ingestion of milk	Shortest on ingestion of milk

The amount of secretion is also proportional to the amount of food consumed. Man secretes up to two litres of gastric juice per day.

**Regulation of gastric juice secretion.** The activities of the gastric glands are regulated by the nervous system and humorally. There are two phases of gastric juice secretion: *reflex* and *chemical (humoral)*. During the first phase gastric juice is secreted reflexly in response to the following stimuli: (a) sight and odour of food; (b) action of food on the receptors situated in the oral cavity; (c) mechanical action of food on the walls of the stomach.

The secretion of juice in response to the sight and odour of food precedes eating and is of a *conditioned reflex character*. Pavlov called this secretion *appetite* or *trigger juice*. This juice is very rich in enzymes and, consequently, possesses great digestive power. Secretion of trigger juice is conditioned by a feeling of appetite, which is a *sine qua non* of normal digestion.

The secretion of juice at the time of eating is due to stimulation of the sensory nerve endings in the mucous membrane of the oral cavity by food. The nervous excitation is transmitted along sensory nerves to the medulla oblongata and thence along secretory nerves to the gastric glands, where it provokes the secretion of gastric juice. Juice secretion in response to stimulation of the receptors situated in

the oral cavity is the result of an *unconditioned reflex*. The existence of this mechanism of juice secretion was demonstrated by Pavlov in his experiments of "sham feeding" of dogs.

In the experiment the animal's oesophagus is transected in the region of the neck and both its ends are sutured to the skin. The oesophagus is usually cut at the same time as a permanent gastric fistula is established. When such an animal eats, the food does not get into the stomach, but falls out of the oesophageal opening on the neck. Nevertheless, gastric juice is secreted, which proves that the secretion in the stomach is regulated reflexly. In response to the stimulation of receptors in the oral cavity gastric juice begins to be secreted 5-6 minutes after the beginning of eating.

Secretion of gastric juice in response to mechanical stimulation of the walls of the stomach is also controlled by an unconditioned reflex. The pressure of the food on the walls of the stomach stimulates the receptors imbedded in them. The nervous excitation is transmitted along nerves to the medulla oblongata and thence to the gastric glands which secrete the juice.

The second phase of gastric juice secretion, the chemical phase, depends on the effect certain chemical substances have on the secretion of the gastric glands. It sets in 15 to 20 minutes after the beginning of eating. Gastric juice is secreted copiously after the ingestion of meat or vegetable broth which contains so-called *extractives*. The products of protein digestion—*albumoses* and *peptones*, and spices and other substances also stimulate the secretion of the gastric glands. It is believed that chemical stimulators of gastric secretion are absorbed from the stomach and intestines into the blood and in this way stimulate the gastric glands. It is possible that chemical substances may also influence the receptors in the walls of the stomach and thereby evoke intensified secretion of the gastric glands reflexly through the nervous system. The effect of the various stimuli on gastric juice secretion is practically simultaneous.

Some substances exert not a stimulatory, but an inhibitory effect on the activity of the gastric glands. One of these substances is fat which delays gastric juice secretion.

### SMALL INTESTINE

The small intestine is a tube 5-7 metres long. It consists of three divisions, namely, the *duodenum*, the *jejunum*, and the *ileum*.

The *duodenum* is situated on the posterior wall of the abdominal cavity on the level of first-third lumbar vertebrae. It is U-shaped and consists of *superior horizontal*, *descending* and *inferior horizontal parts*. The descending part contains the openings of the common bile duct and the pancreatic duct. The former transmits bile, and the

latter carries pancreatic juice. Sometimes there are two pancreatic ducts.

The *jejunum* and *ileum* occupy the middle and inferior parts of the abdominal cavity. Numerous intestinal loops are suspended from the posterior abdominal wall by means of the mesentery (see "Peritoneum"). There is no clear boundary between the jejunum and the ileum.

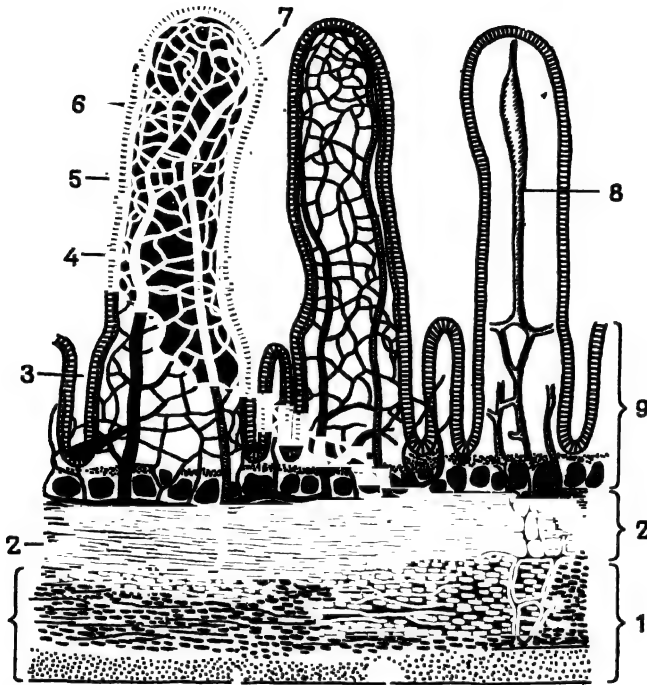


Fig. 79. Structure of intestinal villi

1—muscular coat; 2—submucous coat of small intestine; 3—depression between villi; 4—venous vessel; 5—epithelium of villus; 6—capillary network; 7—arterial vessel; 8—lymph vessel; 9—mucous coat of intestine

(the superior two-fifths of the small intestine, except for the duodenum, are considered the jejunum, and the inferior three-fifths is the ileum).

The wall of the small intestine consists of a mucous coat, a submucous coat, a muscular coat and a serous coat. The mucous coat forms numerous circular folds. The descending part of the duodenum has one longitudinal fold on which there is a papilla. The common bile duct and pancreatic duct mentioned above open on this papilla. The mucous coat of the small intestine contains very many glands which



secrete *intestinal juice* which takes part in digestion. The special feature of the structure of the mucous coating of the small intestine is the presence of villi. The glands of the small intestine have their openings between the bases of the villi.

**Villi** (Fig. 79) are projections of the mucous coat; a villus is about 1 millimetre long. In the lumen of the intestine the villi are covered with columnar epithelium. Under the epithelium there is reticular connective tissue which lodges nerves and blood vessels. In the centre of each villus there is a lymph vessel with a blind ending (*lacteal vessel*). A small artery enters each villus where it divides into capillaries. The capillaries then join again to form a vein leading from the villus. Villi also contain smooth muscle fibres and nerve fibres. Altogether there are about four million villi in the small intestine; nutrients are absorbed into the blood and lymph through the villi.

The *submucous coat* contains lymph nodules situated along the entire length of the small intestine; at the end of the ileum they form aggregates known as *Peyer's patches*. The lymph nodules have a protective function; in some diseases (for example, typhoid fever) they undergo certain changes.

The *muscular coat* of the small intestine consists of two layers, one *longitudinal* and one *circular*. Contractions of the circular layer of muscle fibres result in wave-like movements of the small intestine going from the stomach to the large intestine. These movements are called *peristalsis*. There are also *pendular movements* during which the longitudinal and circular layers of the muscular coat alternately contract and relax in various parts of the intestine.

The movements of the entire intestine are controlled by nerve impulses. The vagus nerve exerts a stimulatory influence and the sympathetic nerve exerts an inhibitory influence. Mechanical stimulation of the intestinal walls intensifies the intestinal movements. Coarse food may therefore stimulate intensified intestinal peristalsis.

The *serous coat* (peritoneum) covers the duodenum anteriorly and completely envelops the jejunum and ileum.

## LIVER

The liver (*hepar*) is a large organ weighing about 1.5 kg (Fig. 80). It is situated in the upper part of the abdominal cavity, in the right and partly in the left hypochondriac regions. It has two surfaces, superior convex and inferior concave, and two margins, posterior blunt and anterior sharp. The superior surface lies close to the diaphragm and the inferior surface faces the stomach and duodenum. A peritoneal fold called the falciform ligament extends to the liver from the diaphragm and divides the liver into two lobes—the larger (right) and the smaller (left). On the inferior surface there are two longitudinal (right

and left) fissures and one transverse fissure which divide the liver from below into four lobes—right, left, quadrate and caudate. The right longitudinal fissure lodges the gall bladder and the inferior vena cava; the left fissure contains the round ligament of the liver. The transverse fissure is called the *porta hepatis*; it gives passage to the *nerves, hepatic artery, portal vein, lymph vessels* and the *hepatic duct*.

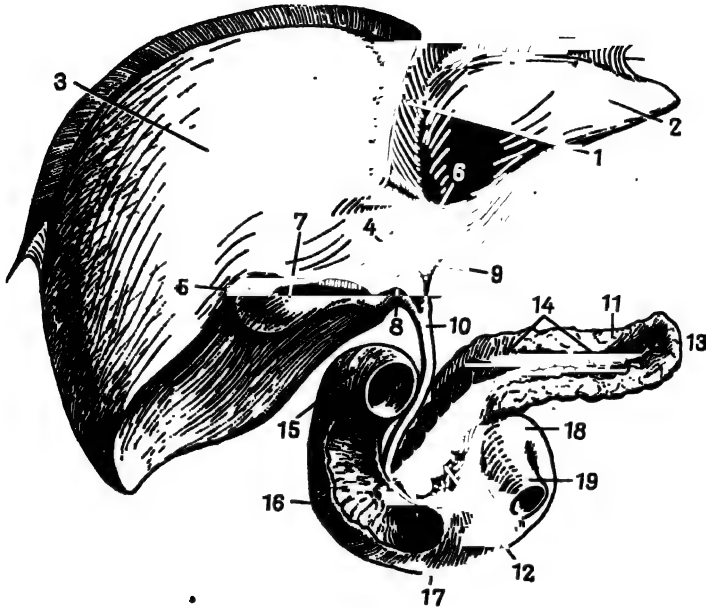


Fig. 80. Liver, gall bladder, duodenum and pancreas

1—falciform ligament; 2—left lobe of liver; 3—right lobe; 4—quadrate lobe; 5—right longitudinal fissure; 6—left longitudinal fissure; 7—gall bladder; 8—bile duct; 9—hepatic duct; 10—common bile duct; 11—pancreas; 12—head of pancreas; 13—tail of pancreas; 14—pancreatic duct; 15—superior horizontal part of duodenum; 16—descending part of duodenum; 17—inferior horizontal part of duodenum; 18—duodenum merging with jejunum; 19—jejunum

The liver is completely enveloped by the peritoneum, except for its posterior margin which is fused with the diaphragm. The anterior margin of the liver lies close to the anterior abdominal wall and is enclosed by the ribs. In some diseases the liver is enlarged. In such cases it protrudes from under the ribs and may be palpated.

The liver consists of numerous lobules, and the lobules consist of gland cells. There are layers of connective tissue between the lobules, which contain nerves, small bile ducts, blood and lymph vessels (Fig. 81). The interlobular blood vessels are branches of the hepatic

artery and the portal vein. Inside the lobules they form an extensive network of capillaries which drain into the central vein at the centre of the lobules. Unlike the other organs, not only arterial blood flows to the liver through the hepatic artery, but also venous blood through the portal vein. The arterial and venous blood flows through a system

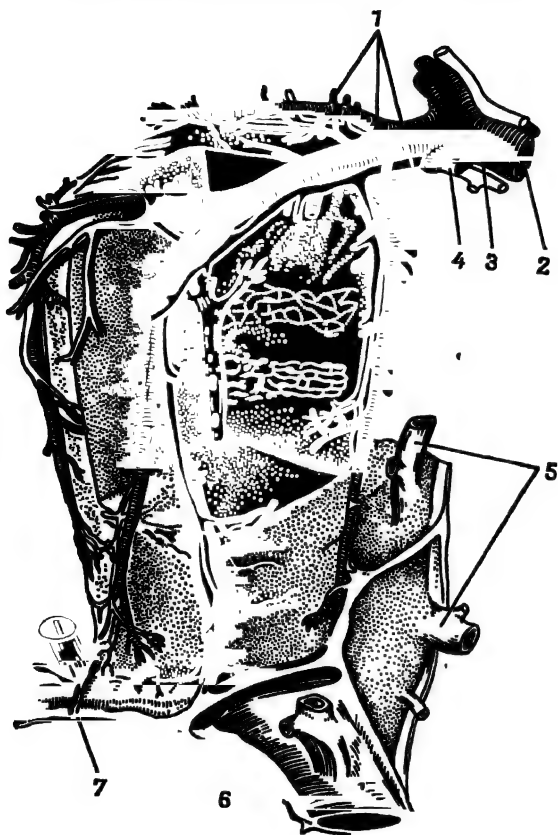


Fig. 81. Lobule of liver (diagram)

1—interlobular blood vessels and bile ducts; 2—portal vein; 3—hepatic artery; 4—hepatic duct; 5—central veins of two adjacent lobules; 6—hepatic vein; 7—fibrous capsule of liver

of blood capillaries in the hepatic lobules and collects in the central veins. The central veins coalesce and form 2-3 hepatic veins which leave the liver and drain into the inferior vena cava. The peculiarities of blood supply of the liver are connected with its functions (see below).

Through the portal vein venous blood flows to the liver from the

unpaired organs of the abdominal cavity: the stomach, pancreas and spleen, the small intestine and the greater part of the large intestine.

In the hepatic lobules between the hepatic cells there are narrow lumens, the bile canaliculi, into which the hepatic cells secrete their bile. The bile passes from these canaliculi into the bile ducts. The bile ducts coalesce and form the hepatic duct which leaves the liver through its porta.

**Significance of the liver.** The liver plays a very important role in the vital activities of the organism. It secretes bile which participates in the digestive process (the significance of the bile will be considered in detail below) and it also has other functions, including participation in carbohydrate, fat and protein metabolism, and a defensive (barrier) function.

The liver participates in carbohydrate metabolism by forming and storing *glycogen*. The nutrients absorbed into the blood from the small intestine pass into the liver through the portal vein. In the liver the glucose brought by the blood is transformed into animal starch, or glycogen. It is deposited in the hepatic cells (as well as in the muscles) as a reserve nutrient. The blood contains only part of the glucose which is gradually consumed from it by the organs. At the same time the glycogen of the liver breaks down into glucose which passes into the blood. Thus the content of glucose in the blood remains unaltered.

The liver participates in fat metabolism when there is a fat deficiency in the food by transforming part of the carbohydrates in the liver into fats.

The liver plays an important part in protein metabolism; in the liver the products of protein breakdown (*ammonium*) form *urea* which is a constituent of *urine*. Moreover, in the liver the excess of protein may apparently be transformed into carbohydrates.

The defensive function of the liver consists in the fact that some toxic substances are detoxified in it. Some of these toxic substances (*indole*, *skatole*, etc.) are formed in the large intestine by putrefaction of proteins and are brought in by the blood through the portal vein. In the liver these substances are transformed into nontoxic compounds and are eliminated from the organism in the urine.

## GALL BLADDER

The gall bladder (see Fig. 80) is situated in the anterior part of the right longitudinal fissure of the liver and serves as a *bile reservoir*. It consists of a fundus, a body and a neck. The neck narrows down and merges with the bile duct which unites with the hepatic duct to form the common bile duct which drains into the duodenum. Bile collects in the gall bladder when no food is being digested. It

is brought to the gall bladder from the liver along the hepatic duct and then along the bile duct. When food enters the duodenum, the gall bladder contracts and the sphincter choledochus (situated at the opening of the common bile duct) relaxes reflexly with the result that bile pours from the gall bladder into the intestine.

### PANCREAS

The pancreas is the second largest digestive gland (see Fig. 80). It is situated behind the stomach on the posterior abdominal wall. The gland consists of a head, a body and a tail. The head is directed to the right and is surrounded by the U-shaped duodenum, while the tail is directed to the left and lies in close proximity to the spleen. The pancreas consists of lobules. The gland cells in the lobules secrete *pancreatic juice*. The pancreatic duct runs inside the gland along its entire length and opens out into the duodenum. In the substance of the gland, between the lobules, there are small areas of special glandular tissue called the islets of Langerhans. These islets function like an endocrine gland (see "Endocrine Glands").

### DIGESTION IN THE SMALL INTESTINE

From the stomach the food passes in small portions in the form of chyme into the small intestine where it undergoes further mechanical and chemical processing. The mechanical processing involves the pendular movements of the intestine, which mix the chyme with the digestive juices and liquefy it still further; this accelerates the subsequent chemical treatment by enzymes. The peristalsis of the small intestine moves the contents down the digestive tract.

Pancreatic juice, intestinal juice and bile act chemically on the food in the small intestine. It is characteristic that large amounts of these juices are secreted for small quantities of chyme. The process of splitting the complex organic substances—proteins, fats and carbohydrates—ends in the small intestine. The digestive process operates most intensely in the upper division of the small intestine, the duodenum.

The final products obtained from the breakdown of food are absorbed from the small intestine into the blood and lymph.

**Composition and properties of pancreatic juice.** Pancreatic juice is a clear alkaline fluid containing the following constituents: (1) *trypsin* which acts on proteins, (2) *amylase* and *maltase* which act on carbohydrates, and (3) *lipase* which acts on fats.

*Trypsin* splits proteins into amino acids, but acts only in the presence of the enzyme called *enterokinase*. This enzyme is produced in the mucous coat of the small intestine and is a constituent of intestinal juice.

*Amylase* and *maltase* split carbohydrates into monosaccharides.

*Lipase* splits fats into *glycerin* and *fatty acids*, the latter interacting with the bile acids and alkalis of intestinal juice and becoming saponified. The activity of lipase sharply increases in the presence of bile. All enzymes of the pancreatic juice retain their activity only in an alkaline medium. About 800 ml of pancreatic juice is secreted in one day. The amount and composition of pancreatic juice, and of all the other digestive juices, vary with the character of the food. For example, much more pancreatic juice is secreted for bread than for milk.

The secretion of pancreatic juice is regulated by the nervous system and humorally. Pavlov showed in experiments on animals that pancreatic juice is secreted in response to stimulation of the receptors of the oral cavity with food. This juice secretion is of a reflex character. The activity of the pancreas is also affected by certain chemical substances. These include *secretin* which is produced in the mucous coat of the duodenum under the influence of the hydrochloric acid brought with the food from the stomach; secretin is absorbed by the blood. The secretion of pancreatic juice is also intensified by other substances (products of the splitting of fats, etc.). Chemical substances exert their influence not only through the blood but also, reflexly, through the nervous system. Pancreatic juice is secreted only during digestion.

**Composition and properties of intestinal juice.** Intestinal juice is secreted by the glands of the mucous coat of the small intestine. It consists of the enzyme called *erepsin* which acts on the intermediate products of protein splitting, the enzymes called *amylase*, *lactase*, etc., which act on various carbohydrates, and the enzyme known as *lipase* which splits fats. Intestinal juice also contains *enterokinase*, mentioned above, which does not split any nutrients directly, but converts inactive *trypsinogen* into active trypsin.

About 1 litre of intestinal juice is secreted during a day. The secretion is excited by mechanical stimulation of the wall of the small intestine when food enters the intestine, and by the action of various other substances. For example, the passage of gastric juice into the small intestine stimulates intensified secretion of its glands. Intestinal juice, like pancreatic, is secreted only during digestion.

**Composition and properties of bile.** Bile is a yellowish-brown, weakly alkaline fluid. It contains water, bile acids, bile pigments, and other organic and inorganic substances. The principal pigment of human bile is *bilirubin*. This pigment is formed from substances present in haemoglobin, the blood pigment, which are liberated when erythrocytes are destroyed.

Bile freshly secreted by the liver (*hepatic bile*) is more fluid and lighter in colour than that collected in the gall bladder (*bladder bile*).

This is due to the fact that in the gall bladder some of the water is absorbed. Bile is continuously being formed in the liver, but it passes into the duodenum only during digestion. Bile contains no enzymes and therefore does not directly split any nutrients. However, it plays a very important part in digestion, especially in the digestion of fats. It intensifies the action of the enzymes present in the intestine, especially the enzyme which splits fats. It helps to emulsify the fat contained in food (break it up into minute globules); emulsified fat is more rapidly split by enzymes. Bile acids help the fatty acids liberated during the splitting of fats to be transformed into readily soluble compounds. Bile also helps to intensify intestinal peristalsis and to secrete pancreatic juice.

Sometimes *gall-stones* are formed in the gall bladder and bile ducts. One of their constituents is *cholesterol*, a lipid present in bile. Gall-stones may cause attacks of sharp pain in the right hypochondrium (*hepatic colic*). Obstruction of the hepatic or bile duct by stones may give rise to jaundice.

Bile is formed in response to nerve impulses coming from the central nervous system. The intensity of secretion is also affected by certain substances called *cholagogues*. These substances include the hydrochloric acid of the gastric juice entering the small intestine, the products of protein splitting, acid liquids, certain mineral waters, etc. It is characteristic that the bile itself greatly stimulates secretion of bile when it enters the digestive tract or the blood.

The liberation of bile from the gall bladder into the duodenum is a reflex action regulated by the nervous system. When the chyme enters the small intestine it stimulates the receptors in the mucous coat. The wall of the gall bladder responds by contracting and the sphincter situated at the end of the common bile duct relaxes. As a result bile pours from the gall bladder into the duodenum. During digestion bile passes from the liver into the intestine, by-passing the gall bladder. Man secretes 700-1,200 ml of bile a day.

### ABSORPTION

The splitting of complex nutrients ends in the small intestine. The nutrients are transformed into simpler substances readily soluble in water and capable of being absorbed and assimilated by the organism.

Absorption is the passage of nutrients from the digestive tract into the blood and lymph. In man absorption takes place mainly in the small intestine; it is a complex physiological process in which the mucous coat of the intestine plays an active role. As noted above, the mucous coating forms numerous projections, villi, through which the absorption is effected. Because of the villi the total surface area

of the small intestine is 4-5 sq m (for comparison, the total surface area of the skin is 1.5 sq m). The epithelial cells covering the villi take an active part in the passage of substances from the intestine into the blood and lymph.

The blood absorbs water and the mineral salts dissolved in it, the amino acids formed as a result of protein splitting, and the monosaccharides which are the products of carbohydrate splitting.

The fatty acids formed by splitting of fats are insoluble in water and cannot be absorbed in this form. They preliminarily interact with alkalis in the small intestine and are transformed into soaps (salts of fatty acids) which in the presence of bile acids are readily soluble and easily absorbed. Glycerin which is also formed by splitting of fats is an easily soluble and readily absorbed substance. When they pass through the mucous coat of the small intestine the glycerin and soaps interact and form a specific human fat which enters the lymph through the lacteal end-capillaries of the villi.

Periodic contractions of the villi, which act as a kind of pump, help absorption in the small intestine. When a villus contracts the contents of its lacteal end-capillary is squeezed into the larger lymph and blood vessels. As the villus relaxes it is refilled with nutrients from the intestine.

It should be noted that some substances are absorbed not only in the small intestine, but also in other divisions of the digestive tract. For example, water, alcohol and salts are absorbed in the stomach. Mainly water is absorbed in the large intestine, although carbohydrates may also be absorbed (this underlies the use of nutritive enemas). Various drugs may be absorbed through the mucous membrane of different divisions of the digestive tract.

## LARGE INTESTINE

The ileum merges with the large intestine in the right ileocaecal fossa. There is a fold of mucous membrane here, called the *ileocaecal valve*, which is so constructed that the contents of the small intestine may freely pass into the large intestine, but cannot move back.

The large intestine is about 1.5 m long and is divided into the following parts (see Fig. 70): the *caecum* with its *vermiform appendix*, the *ascending*, *transverse*, *descending* and *sigmoid colon*, and the *rectum*.

The walls of the large intestine are composed of the same coat as those of the small intestine, although there are some differences in structure.

The mucous coat of the large intestine forms semilunar folds and has no villi. The cells of the mucous coat secrete mucus. There are single lymph nodules all along the mucous coat.



The muscular coat of both the large and small intestines consists of two layers. The longitudinal layer of the large intestine does not cover all its circumference, but is arranged in the form of three bands, the *taeniae coli*. The intestinal wall forms *protrusions* in the intervals between the bands. The serous coat of the large intestine has *digitiform projections* in which fat is deposited; these projections are called *epiploic appendages*. The muscular bands, protrusions and epiploic appendages make the large intestine easily distinguishable from the small intestine.

The *caecum* is situated in the right ileocaecal fossa and is the initial part of the large intestine, i.e., the part which lies immediately below the site where the small intestine merges with the large intestine. This intestine communicates with the vermiform appendix through a small opening closed by a fold of mucous membrane called the *valvula processus vermiformis*.

The vermiform appendix is usually situated below the caecum and descends into the region of the true pelvis, although sometimes it lies behind the caecum. The thickness of the appendix does not exceed 1 cm while its length averages from 7 to 9 cm. The wall of the appendix contains a large number of lymph nodules. Inflammation of the vermiform appendix is a relatively frequent occurrence and is called appendicitis.

The *ascending colon* is a continuation of the caecum; it is situated in the right half of the abdominal cavity, on its posterior wall, and rises to the level of the liver where it is continuous with the transverse colon.

The *transverse colon* lies below the greater curvature of the stomach and is suspended from the posterior abdominal wall by its own mesentery. In the left hypochondrium, near the spleen, it is continuous with the descending colon.

The *descending colon* is situated, like the ascending colon, on the posterior wall of the abdominal cavity, only in its left half. It is continuous with the sigmoid colon.

The *sigmoid colon* lies in the left ileocaecal fossa; it forms several loops and has a mesentery.

The *rectum* is a continuation of the sigmoid colon and lies in the true pelvis. In front of the rectum are the uterus and vagina in females, and the bladder, prostate and seminal vesicles in males. Behind the rectum are the sacrum and coccyx. The mucous coat of the rectum forms 8-10 longitudinal and 2-3 transverse folds. Between the longitudinal folds there are depressions called *rectal sinuses*. The lower part of the rectum is dilated and is called the *rectal ampulla*.

The rectum ends in the anal opening or anus. The anus is surrounded by *two sphincters*, one internal and one external. The internal sphincter consists of smooth muscle tissue and contracts involuntarily.

ily. The external sphincter is formed by striated muscles and is controlled consciously.

### DIGESTION IN THE LARGE INTESTINE

Undigested remains of food pass from the small intestine into the large intestine. These remains consist mainly of cellulose which is not broken down either in the stomach or in the small intestine. The main processes operating in the large intestine are the *formation of faeces* and the *absorption of water*. *Fermentation* and *putrefaction* of the food remains also take place in the large intestine. The large intestine contains a great number of different bacteria (*intestinal flora*). Some of them cause fermentation of carbohydrates, while others cause putrefaction of proteins. Both are responsible for the formation of gases. The breakdown of proteins is also accompanied by the production of certain *toxic substances* (*indole, skatole*, etc.), some of which are absorbed into the blood and pass into the liver. Formation of toxic substances increases in cases of constipation.

Water is absorbed partly in the small intestine, but mainly in the large intestine. Almost 4 litres of water is absorbed in the large intestine per day leaving only 130-150 g of faeces.

The faeces are composed of undigested remains of food, mucus, dead epithelial cells and a large number of bacteria from the large intestine. The latter make up about one-third of the total weight of the faeces. The colour of the faeces depends on the disintegrated bile pigments, and the amount of faeces depends on the quantity and composition of the food. The faecal masses collect in the rectum. The food remains are moved through the large intestine as a result of contractions of its walls.

### DEFAECATION

Evacuation of the bowels is called *defaecation*. Adults defaecate once or twice a day, and infants and young children more frequently. Defaecation is regulated by the nervous system and is a reflex response to stimulation of the lower parts of the large intestine with faeces. It usually occurs only when the pressure of the faecal masses on the walls of the rectum reaches a certain intensity (about 20 mm Hg), which stimulates the receptors imbedded in the mucous coat of the intestine. The response is reflex contraction of the muscular coat of the intestine and relaxation of the anal sphincters. Simultaneously the muscles affecting the prelum abdominale and the muscle raising the anus (*levator ani*) contract, and the faecal masses are expelled. The defaecation centres, i.e., those controlling the defaecation reflex, are located in the floor of the fourth ventricle (*medullary defaecation*

centre) and in the second, third and fourth sacral segments of the spinal cord (*spinal defaecation centre*); but defaecation is also under the control of the cerebral cortex; proof of this is the voluntary retention of the faeces.

Sometimes the stools are liquid and frequent (diarrhoea). At other times the bowels are evacuated infrequently (once in two or three days or even less frequently) and with difficulty (constipation). These morbid states are usually accompanied by disturbances in intestinal peristalsis.

### PERITONEUM

The peritoneum is a serous membrane which lines the interior surface of the abdominal cavity and envelops the abdominal organs. It is a thin, lustrous layer moistened by fluid. The part of the peritoneum which lines the interior of the abdominal cavity is called the *parietal* peritoneum, and the part surrounding the viscera is known as the *visceral* peritoneum. Between the two parts of the peritoneum is a slit-like space called the *peritoneal cavity* which contains a small amount of *serous fluid* which moistens the two adjoining parts and thereby reduces friction during movement of the abdominal organs.

In many places the peritoneum extends from the abdominal walls to the organs and forms transitional folds. All of the folds of the peritoneum are usually divided into *ligaments*, *mesenteries* and *omenta*. The falciform ligament of the liver, mentioned above, is an example of a peritoneal ligament.

The peritoneal folds on which the intestinal loops are suspended from the posterior abdominal wall are called *mesenteries*. Each mesentery consists of both parts of the peritoneum between which there are layers of loose connective tissue, nerves, blood vessels, lymph vessels and nodes. The jejunum, ileum, transverse colon, sigmoid colon and vermiform appendix all have mesenteries.

An *omentum* is a peritoneal fold with fat between the two layers. There are two omenta—the great omentum and the lesser omentum. The great omentum consists of four layers of the peritoneum and hangs down as an apron from the greater curvature of the stomach; anteriorly it covers the abdominal organs lying below the stomach and fuses with the transverse colon. That part of the great omentum situated between the stomach and the transverse colon is called the gastrocolic ligament. The lesser omentum consists of two peritoneal layers, and extends from the porta of the liver to the lesser curvature of the stomach and the initial part of the duodenum. The right part of the lesser omentum contains the common bile duct, the portal vein and the hepatic artery between its two peritoneal layers.

The abdominal organs occupy different positions with respect to the peritoneum (Fig. 82). Some organs are enveloped by the perito-

neum and this is known as an intraperitoneal position; other organs are covered on three sides by the peritoneum, and their position is known as mesoperitoneal; still other organs are covered only on one side, and their position is referred to as an extraperitoneal position. The stomach, jejunum, ileum, caecum, vermiform appendix, transverse colon, sigmoid colon, upper part of the rectum, and the spleen lie in an intraperitoneal position. The ascending colon, descending colon, middle part of the rectum, the liver, uterus, gall blad-

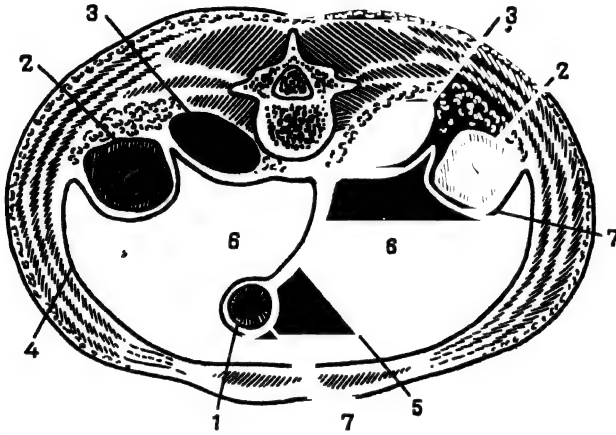


Fig. 82. Positions of organs relative to peritoneum (diagram)

1—intraperitoneal position; 2—mesoperitoneal position; 3—extraperitoneal position; 4—parietal peritoneum; 5—mesentery; 6—peritoneal cavity; 7—visceral peritoneum

der and urinary bladder are covered by the peritoneum on three sides. The duodenum, lower part of the rectum, the pancreas, kidneys and ureters are in an extraperitoneal position.

The position of organs in relation to the peritoneum must be taken into consideration for operations on abdominal organs. When the abdominal cavity is opened the intraperitoneal organs can be palpated on all sides, the mesoperitoneal on three sides, and the extraperitoneal only on one side.

The peritoneum plays an important role. It participates in metabolism between the serous fluid of the peritoneal cavity, the blood and the lymph. The peritoneum protects the internal organs from friction against each other and helps them to slip over each other. The importance of the peritoneum becomes particularly clear in diseases of the abdominal organs because it separates the focus of inflammation from the rest of the abdominal cavity. This results in the formation of adhesions. Inflammation of the peritoneum is called *peritonitis*.

## *Metabolism.* *Vitamins*

Metabolism is one of the principal vital functions of the organism. According to F. Engels' definition, "Life is the mode of existence of protein bodies, the essential element of which consists in *continual metabolic interchange with the natural environment outside them*, and which ceases with cessation of this metabolism, bringing about the decomposition of the protein"\* . Metabolism consists of two interconnected processes; the process of transforming food into living tissue, called *assimilation* or *anabolism*, and the process of breaking down substances, called *disassimilation* or *catabolism*. Complex substances which become part of the cells and intercellular structures are continuously being formed in the living organism. At the same time complex organic substances are being broken down into simpler ones. The final products of metabolism, which cannot be transformed by the organism, are eliminated through the excretory organs.

The nutrients consumed by the organism are not only used for building tissues, but are also sources of the energy used by the organism in its vital activities.

Metabolism involves proteins, carbohydrates, fats, water and mineral salts. In addition to these substances, the organism requires vitamins.

Usually the metabolism of each substance is considered separately. It should be remembered, however, that in the living organism the metabolism of one substance, such as protein, is connected with the metabolism of the other substances.

\* F. Engels. *Dialectics of Nature*, Foreign Languages Publishing House, Moscow, 1954, p. 396.

Metabolism is subject to humoral regulation and regulation by the nervous system. The fact that metabolism in the organs and tissues is controlled by the nervous system was established by Ivan Pavlov and confirmed by the investigations of many other scientists (K. Bykov and others). This influence of the nervous system is called a trophic influence.

Humoral influence on metabolism is exerted through the blood by hormones secreted by the endocrine glands.

### PROTEIN METABOLISM

In the digestive tract the proteins ingested with the food are acted on by enzymes present in the gastric, pancreatic and intestinal juices. During digestion they are split into amino acids which are absorbed into the blood in the small intestine. The blood then transports the amino acids throughout the organism. In the cells of the organs and tissues the amino acids are converted into human proteins. At the same time some of the proteins forming part of the organs and tissues, and the amino acids present in the organism but not being used to form living matter, are decomposed and liberate energy. It has been found that one of the products of protein decomposition is glucose, which then undergoes further oxidation. The end products of protein breakdown in the organism are water, carbon dioxide and nitrogenous substances, such as ammonia, uric acid, etc. The ammonia, which is a toxic substance, is converted into urea in the liver. The products of protein decomposition, like those of other nutrients, are eliminated from the organism through the excretory organs.

*The daily protein requirement is about 100 g. No proteins are stored in the organism.* The organs and tissues of an adult assimilate enough proteins to replace the decomposing proteins of the organism. In children the synthesis of proteins exceeds decomposition.

Protein metabolism in the organism may be estimated from the metabolism of nitrogen. Proteins contain an average of 16 per cent nitrogen, i.e., the weight of proteins is 6.25 times that of the nitrogen they contain. Therefore the protein content of food can be calculated if the amount of nitrogen is known. The amount of nitrogen present in the wastes eliminated from the organism gives the amount of proteins which have been decomposed in the organism.

There is a so-called *nitrogen balance* in a healthy adult, i.e., the amount of excreted nitrogen equals the amount ingested. Severe diseases and starvation are accompanied by a negative nitrogen balance, i.e., more nitrogen is excreted from the organism than is ingested. In children the nitrogen balance is positive, i.e., the amount of ingested nitrogen exceeds the amount excreted. This is because of the intensive growth of the various tissues in children.

### CARBOHYDRATE METABOLISM

In the digestive tract the *complex carbohydrates* or *saccharides* present in food are subjected to the action of the enzymes present in the saliva and the pancreatic and intestinal juices. They are transformed into simple sugars, mainly glucose. In the small intestine glucose is absorbed into the blood and delivered to the organs; for example, the portal vein carries it to the liver. In the organs, particularly in the liver and muscles, glucose is converted into animal starch, glycogen, which is a constituent of the cytoplasm of cells. The glycogen in the liver is a reserve material and when necessary it is reconverted into glucose which passes into the blood and is transported throughout the organism. The glucose content in the blood is usually constant (0.1-0.12 per cent). The glycogen of the muscles and other organs breaks down and liberates energy. A particularly large amount of glycogen is broken down when the muscles are working; the energy liberated is used for mechanical work and as a source of heat. It has been established that glycogen is deposited in the nerve cells and that the activity of the nervous system involves the utilization of carbohydrates. *The end products of carbohydrate breakdown in the tissues are water and carbon dioxide.*

When insufficient carbohydrates are ingested with the food they may be formed from proteins and fats. Unlike proteins and fats carbohydrates easily break down in the organism and are the chief source of energy. *Man's daily carbohydrate requirement is 450-500 g.*

### FAT METABOLISM

In the digestive tract the fats contained in food split under the action of the enzymes present in pancreatic and intestinal juices (with the participation of bile) into glycerin and fatty acids, the latter being saponified. During absorption, in the mucous coat of the small intestine the glycerin and fatty acids are reconverted into *specific human fat* which passes into the lymph (p. 156). From the lymph it enters the blood and is carried all through the organism. Fats are utilized as plastic material and form part of the various tissues (for example, nervous tissues). At the same time part of the fats is oxidized and a large amount of energy liberated. The end products of the breakdown of fats are water and carbon dioxide. Any extra fat is deposited as a reserve. Fat is deposited in the subcutaneous layer, perirenal cellular tissue and the great omentum. Fat may be formed in the organism from proteins and, especially, carbohydrates if they are ingested in excessive amounts. *The daily fat requirement of a human adult averages 100 g.*

## WATER AND SALT METABOLISM

Water is a constituent of all tissues of the organism and is present in the cells and extracellularly. In the cells it is chemically combined with proteins and other substances of the cytoplasm. Extracellularly it forms the basis of tissue fluid. It also makes up the main part by volume of the blood plasma and lymph, and is the solvent of various organic substances and inorganic compounds. The total amount of water in the body of a human adult is up to 70 per cent of the body weight.

Water takes part in the different physiological processes. The splitting of nutrients in the digestive tract, the absorption and transportation of nutrients to the organs, metabolism in the tissues and other processes in the organism all involve water. The importance of water is indicated by the fact that a person deprived of water perishes within a few days.

*The daily water requirement of a human adult averages 2-2.5 litres.* This requirement varies with climatic and working conditions. It increases in hot weather and during work in hot shops.

The water delivered to the digestive tract is absorbed into the blood in the small and large intestines. From the blood it passes into the tissues together with nutrients and salts. A small amount of water is liberated in the tissues during the decomposition of organic substances. From the tissues it passes into the blood and lymph together with the products of decomposition. Water is eliminated from the organism mainly through the kidneys, but also through the skin, lungs (in the form of water vapours) and with the faeces. Under unfavourable conditions the water balance of the organism may become disturbed.

For example, excessive loss of water (prolonged diarrhoea, vomiting) may cause dehydration of the tissues.

Water metabolism is closely associated with the metabolism of mineral salts, which play a very important role. Various salts are constituents of the different tissues and affect the functions of the entire organism. For example, the bones and teeth contain large amounts of *calcium* and *phosphorus*. *Iron* is a constituent of haemoglobin and participates in the transportation of oxygen. *Chlorine* is a component of *hydrochloric acid* contained in gastric juice. *Iodine* is essential for the formation of the thyroid hormone; *sulphur* and *zinc* are constituents of the pancreatic hormone. *Cobalt* is necessary for haematopoiesis (formation of blood); trypsin contains *chromium*. Ions of various elements are present in the blood plasma, tissue fluid and lymph. Normally the concentration of salts in the tissues is fairly constant; they maintain a *constant osmotic pressure* and *acid-base balance*. The direct connection between water and salt metabolism



is indicated by the fact that the volume of water in the blood and tissue fluid depends on the amount of salts, primarily sodium, they contain. Various chemical elements are connected with the activity of the nervous system, heart action, work of the muscles, blood clotting, etc.

The total amount of mineral substances in the human body makes up about 4.5 per cent of the body weight. These substances are ingested with the food and are eliminated from the organism in the urine, sweat and faeces.

Diseases are accompanied by various changes in metabolism; sometimes these changes are the main signs of disease (diseases of metabolism). Gout is an example; in this condition the uric acid content in the blood increases and salts of the acid are deposited in joints, tendons and cartilages. As a rule, changes in metabolism are observed in cases of dysfunction of endocrine glands and in cases of vitamin deficiency.

### VITAMINS

**Importance of vitamins. Concept of avitaminoses.** Vitamins are special organic substances which are indispensable for the organism. They do not provide energy and are not plastic materials, but they participate in metabolism as *catalysts*. They are necessary for the formation of tissue enzymes which influence the transformation of substances in the cells and tissues of the organism. N. Lunin, a Russian doctor, was the first to establish (in 1880) the presence of these substances (later named vitamins) in the food. About 20 vitamins are known today. They are designated by letters A, B, C, D, K, P, etc. The chemical composition and physiological role of most of the vitamins have been determined. Some vitamins (B and C) are water-soluble, while others (A, D, E, K) are soluble only in fats. The daily requirement of vitamins is measured in milligrams and even parts of a milligram. Fresh, varied food usually contains enough vitamins for the organism. The processing or long storage of food may destroy some vitamins. For example, the boiling of food destroys the greater part of vitamin C. Prolonged deficiency of any vitamin results in a disease known as *avitaminosis*. Insufficient intake of any vitamin leads to a morbid state known as *hypovitaminosis*. Most avitaminoses are accompanied by reduced working capacity, rapid fatigue, a sharp decrease in the resistance of the organism to infection, incorrect development and retarded growth (in children), etc. There are also specific disturbances characteristic of each avitaminosis. Various changes, although less pronounced, are also observed in hypovitaminoses.

Vitamins are widely used for medical purposes; many of them are produced synthetically.

**Vitamin A** influences growth. Experiments on animals show that

the lack of this vitamin results in retarded growth. It is also necessary for the maintenance of normal epithelial tissues in the organism. *A-avitaminosis* is accompanied by morbid changes in the epithelium of the cornea, the respiratory and digestive tracts, and of other organs. A dryness and keratinization of the skin and an increase in pigmentation are observed. In severe cases xerophthalmia (dryness of the eye) may develop, which may lead to leucoma of the cornea and loss of vision (Fig. 83). The earliest sign of A-avitaminosis in man is *nyctalopia* (or night blindness).

In such patients vision is abnormally poor or fails completely when it is dark. *Vitamin A is plentiful in butter, liver, egg yolk, milk and, especially, in fish liver oil.* Many vegetables and fruits (*carrots, spinach, tomatoes, etc.*) contain *carotene*, a substance whose composition closely resembles that of vitamin A. In the organism of man (and animals) vitamin A is formed from carotene in the liver.

Vitamin A is relatively stable; it is not destroyed by boiling. *The daily vitamin A requirement is 1-2 mg (carotene—3-5 mg).* Metabolic disturbances, anaemia, and other changes have been observed when excessive amounts of vitamin A are consumed.

**Vitamin B**, or vitamin B complex, represents a group of eleven vitamins.

It includes *vitamin B<sub>1</sub>, nicotinic acid, riboflavin, vitamin B<sub>6</sub>, folic acid, vitamin B<sub>12</sub>, etc.* The common feature for this group is that they all contain nitrogen. Each of these vitamins differs from the rest in chemical structure and in the effects it produces in the organism.

*Vitamin B<sub>1</sub>, or thiamine,* plays a very important part in metabolism, especially that of carbohydrates. A deficiency of this vitamin is responsible for the development of the disease called *beriberi*. The signs of this disease are cardiovascular disorders and motor disturbances to the point of paralysis. In these cases it is mainly the peripheral nervous system which is affected (polyneuritides). Beriberi occurs in countries where rice is the principal food. Vitamin B<sub>1</sub> is present in peas, dry yeast, egg yolk, and the husks of certain cereals. In the human organism vitamin B<sub>1</sub> is not formed from other substances and is not deposited as a reserve. *The daily vitamin B<sub>1</sub> requirement is 2 mg.*



Fig. 83. Xerophthalmia (development of leucoma of cornea)

**Vitamin PP (nicotinic acid)** plays an important part in carbohydrate metabolism in tissues and participates in other forms of metabolism. It affects the activity of the digestive glands and haematopoietic organs. *It is present in rice and wheat bran, milk, eggs, cabbage, tomatoes, lettuce, yeast, etc.* Nicotinic acid deficiency in the organism is one of the causes of the disease known as *pellagra*. The specific manifestations of this disease are changes in the structure of the skin (keratinization) with subsequent and gradual impairment of the digestive system (diarrhoeas) and changes in the nervous system (mental disturbances). The daily vitamin PP requirement is 15-25 mg.

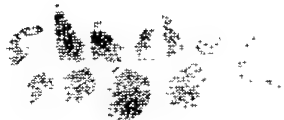


Fig. 84. Appearance of gums in scurvy

The daily vitamin PP requirement is 15-25 mg.

**Vitamin B<sub>2</sub> (riboflavin)** participates in the metabolism of carbohydrates and other substances, and influences respiration, haematopoiesis and the activity of the nervous system; it also takes part in the synthesis of visual purple. *This vitamin is found in yeast, liver, rye bread and certain other products.* A riboflavin deficiency leads to morbid changes in the skin, loss of hair, changes in the nervous system and in the eyeballs; it may give rise to trophic ulcers and other disturbances. *The daily vitamin B<sub>2</sub> requirement is about 2 mg.*

**Vitamin B<sub>6</sub>** participates in the metabolism of proteins, fats and sulphur. *It is plentiful in liver, meat, fish, yeast, peas and other leguminous plants.* In cases of B<sub>6</sub> avitaminosis man exhibits changes in the nervous system and skin.

**Vitamin B<sub>12</sub>** influences the haematopoietic process by participating in the synthesis of proteins required for the maturation of erythrocytes. B<sub>12</sub> avitaminosis is characterized by disturbances in haematopoiesis. This disease develops not only as a result of vitamin B<sub>12</sub> deficiency, but also as a result of morbid states of the stomach and small intestine, when absorption of this vitamin from the food is impaired.

**Vitamin C**, or ascorbic acid, is an antiscorbutic. A deficiency of this vitamin gives rise to *scurvy*, a disease known since antiquity. It affected people who travelled for long periods of time and those whose diet lacked vegetables and fruit. Scurvy develops gradually. The signs of the disease include bleeding gums (Fig. 84), loosening and falling-out of teeth, and subcutaneous and intramuscular haemorrhages. *Large amounts of this vitamin are found in rose-hips, black*

*currants, tomatoes, cabbage, onions, lemons, orange, etc.* Vitamin C is comparatively unstable and its content in various foodstuffs depends on the length and methods of their storage. It is usually plentiful in fresh vegetables and fruit. *The daily vitamin C requirement is about 50-60 mg.* Lemons and red pepper contain vitamin P (*citrin*). It has been established that scurvy is the result not only of C-avitaminosis, but also of P-avitaminosis.

**Vitamin D** is antirachitic. A deficiency of this vitamin in children leads to development of *rickets* (Fig. 85). The signs of rickets in chil-

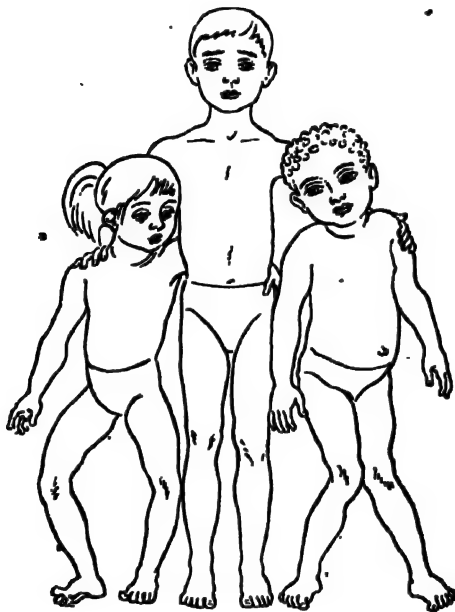


Fig. 85. Middle—healthy child; either side—rachitic children of the same age

dren are retardation in growth and development, a softening and curving of the bones, delayed dentition, late closure of fontanelles, etc. Children affected with rickets exhibit thickenings on the ribs (rachitic rosary), changes in the shape of the thorax (pigeon breast), and an enlarged head.

Vitamin D deficiency is accompanied by disturbances in the metabolism of calcium and phosphorus salts with the result that no calcium is deposited in the bones and the bones soften.

*Vitamin D is found in large quantities in the same foodstuffs as vitamin A, i.e., fish liver oil, butter, liver, egg yolk and milk.* A substance

called *ergosterol* which can be transformed into vitamin D under the influence of ultraviolet irradiations has been discovered in vegetables and meat. A similar substance is present in large amounts in the human skin. For this reason rachitic patients are not only given vitamin D, but are also exposed to sunlight or a quartz mercury vapour lamp. The daily vitamin D requirement of a child is 0.015-0.02 mg, and that of an adult—0.025 mg. Large doses of vitamin D are harmful (they cause excessive deposition of calcium salts in various organs and a disturbance in fat metabolism). There are several forms of vitamin D, but the most active one is *vitamin D<sub>3</sub>*.

**Vitamin E** (tocopherol) influences the function of reproduction. It has been established in experiments on animals that a vitamin E deficiency leads to sterility. E-avitaminosis is accompanied by disorders of the sexual function, inflammation of the skin, and other disturbances. *The vitamin is found in meat, egg yolk, wheat grains, etc.*

**Vitamin K** is antihæmorrhagic and is necessary for the formation of prothrombin (in the liver) which participates in blood clotting. *Vitamin K is present in spinach, lettuce, cabbage, carrots, etc.* In man (and in some animals) this vitamin is produced by bacteria found in the large intestine. K-avitaminosis diminishes the ability of the blood to clot and results in bleeding (for example, from the gums) and hæmorrhages (into joints, retina, etc.).

### ENERGY METABOLISM

In the organism energy is continuously expended for the performance of various functions (muscular work, secretory activity of glands, nervous activity, etc.) and is simultaneously and continuously formed. The organism derives its energy from the food it consumes from the external environment. Under the action of tissue enzymes the food is transformed into simpler substances and energy is liberated. Muscular, secretory, nervous and other types of activity involving the expenditure of internal energy is accompanied by the liberation of heat. It has been established that the intensity of metabolism can be measured by the amount of heat formed in the organism. Oxidation of 1 g of protein in the tissues yields 4.1 Cal, oxidation of 1 g of carbohydrates also yields 4.1 Cal, and oxidation of 1 g of fat yields 9.3 Cal. If we know the amount of these substances ingested by the organism, we can calculate the amount of energy they contain, i.e., the energy intake. It should be remembered that not all of the nutrients are assimilated by the organism and some are eliminated undigested. It has been demonstrated experimentally that about 90 per cent of the nutrients ingested by the organism is assimilated. The energy expenditure of the organism can be measured; there are several

methods of doing this. One of them consists in determining (in special chambers) the quantity of heat man gives off into the surrounding environment.

### BASAL METABOLISM

Basal metabolism is the minimum amount of energy expenditure necessary to maintain vital activity (maintenance of heart activity, contraction of respiratory muscles, etc.) when the body is at complete rest in a warm atmosphere 12-18 hours after the intake of food. The basal metabolism of an adult ranges from 1,000 to 2,000 Cal a day for men and from 1,000 to 1,700 Cal for women. In addition to sex differences, basal metabolism also depends on the person's weight, height and age. When a man is working additional energy is expended (*working metabolism*). The additional energy metabolism depends on the type and duration of the work. For example, it has been found that the total energy expenditure (basal metabolism + working metabolism) of a mental worker is 2,700-3,000 Cal a day. This expenditure sharply increases during hard physical work and may amount to 5,000 Cal and even more.

### NUTRITION

Nutrition is one of the most important factors affecting man's health and working capacity. The normal development of a child very largely depends on proper nutrition. Nutrition is one of the most important therapeutic factors in medical practice.

The quantity and composition of food required by man depend on age, stature, character of work and other factors. In making up a diet it is necessary to consider the needs of the organism not only in proteins, carbohydrates and fats, but also in vitamins and mineral salts. The diet must contain the different nutrients in definite proportions. It must contain proteins and fats of animal origin, and vegetable fats and proteins must not be excluded. It should be remembered that different foodstuffs are differently assimilated. A variety of foods best satisfies all the requirements of rational nutrition. Assimilation of food depends on how it is prepared, and under what conditions and how many times a day it is ingested. Palatable food taken at definite hours is digested better and more rapidly. Special tables are used to determine the caloric value of different foods.

The prescribed diet must be strictly obeyed in the treatment of patients. Variations from the prescribed diet may be the cause of severe complications in the patient's condition.

### HEAT PRODUCTION AND HEAT LOSS

The temperature of the human body is maintained constant independent of the surrounding temperature. This temperature is main-

tained by regulation of heat production and heat loss. In the organism heat is continuously produced in all organs as the result of oxidation of nutrients. A large amount of heat is produced in the muscles, especially during physical work. There is a direct interdependence between metabolism and heat production; increased metabolism is accompanied by increased heat production and decreased metabolism is accompanied by decreased heat production. Regulation of heat production is basically due to changes in metabolism. For example, if the temperature of the external environment drops, the metabolism and, consequently, the heat production increase. A vivid example of this interdependence is the trembling of muscles when the body cools down. Receptors in the skin are stimulated by the cold and this evokes a reflex contraction of the muscles, accompanied by increased metabolism and increased heat production.

Heat production is accompanied by a process of heat loss. The blood flowing through the organs becomes heated and gives off any excess of heat to the surrounding environment. Heat is lost mainly through the skin by heat radiation and heat convection, but also by the evaporation of sweat. Part of the heat is lost with exhaled air, and in the urine and faeces. Radiation and convection of heat through the skin occur only when the temperature of the surrounding air is lower than the temperature of the body. When the air temperature is high heat is lost mainly, or exclusively, through perspiration. The regulation of heat loss depends largely on the change in volume of the blood flowing through the cutaneous vessels and on the intensity of perspiration. When the cutaneous vessels are dilated and there is an increased flow of blood, heat losses increase; when these vessels are constricted and there is a decreased flow of blood, heat losses diminish.

The process of heat production and heat loss are regulated by the nervous system through the heat-regulating centres situated in the hypothalamus. It has been established in experiments on animals that mechanical (a prick with a special needle) or electrical stimulation of this area of the brain evokes a rise in body temperature.

Normally the heat-regulating centres become excited when the temperature receptors of the skin are stimulated and under the influence of the temperature of the blood flowing to the centres. For example, when the skin receptors are stimulated with cold the impulses are transmitted to the heat-regulating centres. At the same time the temperature of the blood bathing the heat-regulating centres may change somewhat. The heat-regulating centres respond to these stimuli in two ways: one causes increased metabolism in the tissues, which increases heat production, and the other causes constriction of the cutaneous blood vessels, which leads to diminished heat loss. This prevents the cooling of the organism.

In the organism of a healthy person heat production and heat loss are balanced; as much heat is eliminated into the surrounding environment as is produced. As a result of this balance the temperature of the body is maintained constant.

The average body temperature of a healthy person, measured in the axilla, ranges from 36.5 to 36.9°C. The temperature of infants is measured in the rectum (37-37.5°C). There are regular slight variations in temperature during each day. The lowest temperature is observed between 4:00 and 6:00 a.m., and the highest between 4:00 and 6:00 p.m. The temperature recorded at different times of the day may be used to draw a daily temperature curve.

Many diseases are accompanied by a rise in body temperature, which is due to disturbed heat regulation. A rise in body temperature above 41°C is very harmful for the organism because it impairs the vital processes (these processes are possible only within definite temperature limits). A high body temperature is accompanied by a sharp increase in metabolism, greater decomposition of the organism's own proteins (negative nitrogen balance), tachycardia and an associated elevation of blood pressure, accelerated respiration, etc. The body temperature rises during hard muscular work, especially when the air temperature is high. In such cases man may suffer a heat stroke.

In some cases, for example, during prolonged cooling, the temperature of the body drops below normal. A drop in body temperature (hypothermia) is sometimes produced artificially in surgical intervention (for example, during operation on the heart). This leads to decreased metabolism in the organism and lowers the oxygen requirements of the tissues. Under such conditions the tissues can withstand an oxygen deficiency in the blood for a longer period of time.



## CHAPTER 7

# *Urogenital System*

The urogenital system combines two systems of organs: urinary and genital. The two systems perform different functions, but are intimately related embryologically and anatomically.

### URINARY SYSTEM

#### *General Information*

The vital activities of an organism involve the decomposition of proteins, fats and carbohydrates in the different tissues, accompanied by liberation of energy and formation of compounds called end products of metabolism.

The products of metabolism enter the blood and thus pass into the excretory organs through which they are voided from the organism. Most of the products of decomposition are eliminated in the urine by the urinary organs.

The urinary system consists of the kidneys, ureters, urinary bladder and urethra. Urine is formed in the kidneys which are the main organ of excretion. It then passes through the ureters into the urinary bladder which serves as a reservoir. The urine is voided through the urethra to the exterior.

Besides the kidneys, the skin and lungs also take part in excretion. The products of protein metabolism, water and salts are excreted from the organism in the sweat through the skin. Carbon dioxide and water (in the form of water vapour) are eliminated through the lungs.

#### *Kidneys*

The *kidneys (renes)* are a paired organ situated in the lumbar region, on the posterior abdominal wall, at the level of the twelfth

thoracic and first-second lumbar vertebrae (Fig. 86). A kidney weighs about 150 g.

The kidney is covered by *membranes*. The connective tissue membrane which directly adheres to the kidney is called the *fibrous capsule*. This capsule is surrounded by perirenal fat called the *adipose capsule*. The outermost membrane of the kidney is known as the *renal fascia*.

The kidney is bean-shaped. It has superior and inferior ends (most commonly called poles), anterior and posterior surfaces, and lateral and medial borders. On the medial border there is a fissure called the *hilus renalis* which transmits the ureter, nerves, renal artery, renal vein and lymphatic vessels. Inside the kidney the hilus expands into a central cavity called the *renal sinus*. The latter contains the major and minor renal calyces, the renal pelvis, nerves and blood vessels.

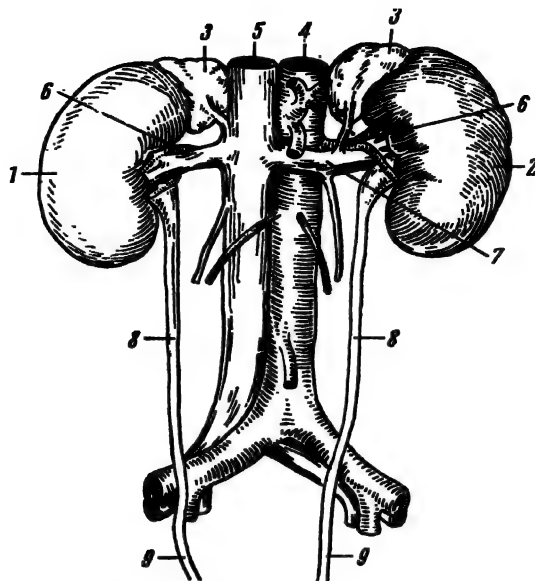
A section of the kidney reveals two substances, called the *cortical* and *medullary* substances (Fig. 87). The cortical substance is situated along the periphery of the kidney and projects into the medullary substance in the form of columns. The medullary substance is situated inside the cortical substance and takes the form of lobules or *renal pyramids*. The apices of the pyramids converge towards the renal sinus and are surrounded by the minor calyces (Fig. 87).

The cortical and medullary substance of the kidney contains a large number of uriniferous tubules and blood vessels. The uriniferous tubules make up the parenchyma of the kidney. They are very fine, variously-shaped tubes (Plate III) with walls of renal epithelium. The blood vessels in the renal substance are of different diameters and constitute branches of the renal artery and renal vein.

The uriniferous tubules are intimately connected with minute blood vessels and make up the so-called *nephrons* (structural units of the kidney). The urine is formed in the nephrons. The two kidneys contain more than *two million nephrons*.

The initial part of each nephron is the so-called *renal corpuscle* (also known as the Malpighi-Shumlyansky's corpuscle) (Plate III). A renal corpuscle consists of a tuft of capillary loops (glomerulus) and a capsule (glomerular capsule also known as Shumlyansky-Bowman's capsule). The latter looks like a two-walled cup. It is continuous with the uriniferous tubule called the proximal convoluted tubule and is followed by a looped tubule (loop of Henle) which communicates with the distal convoluted tubule. All these tubules are part of the nephron.

The relationship between the blood vessels and uriniferous tubules of the nephron plays an important role in the process of urine formation. A blood vessel called an afferent vessel enters the glomerular capsule and branches into capillaries which form the glomerulus of the renal corpuscle. From the glomerulus the blood flows into an



**Fig. 86. Kidneys and ureters**

1—right kidney; 2—left kidney; 3—adrenal glands; 4—aorta; 5—inferior vena cava; 6—renal artery; 7—renal vein; 8 and 9—ureters



**Fig. 87. Kidney (section)**

1—major calyx; 2—minor calyces; 3—renal pelvis; 4—ureter; 5—medullary substance (pyramids); 6—papillae; 7—cortical substance of kidney

afferent vessel. The afferent vessels, glomeruli and efferent vessels contain arterial blood. It should be noted that efferent vessels have smaller diameters than afferent vessels. This increases the pressure in the glomerular capillaries, which is important for the process of urine formation. The efferent vessels in their turn divide into a dense network of capillaries which supply the tubules of the nephrons. The arterial blood changes to venous blood while flowing through these capillaries. Unlike other organs, the kidney has not one, but two systems of capillaries; this is connected with the function of urine formation.

In addition to the uriniferous tubules in the nephrons the kidneys also have collecting tubules which eliminate the urine but take no part in its formation. The collecting tubules unite and their ostia open into the minor calyces on the apices of the pyramids in the medullary substance of the kidneys.

**Process of urine formation.** The process of urine formation in the nephrons operates in two phases; the first phase is the formation of *primary urine*, and the second phase is the formation of *secondary* or *final urine*.

The primary urine\* is formed in the renal corpuscles by *filtration* from the blood flowing through the glomerular capillaries. Part of the water and some of the other substances present in the blood pass through the wall of the glomerulus and the visceral layer of the glomerular capsule into the lumen of the capsule. The chemical composition of primary urine corresponds to blood plasma, but is devoid of proteins. The process of primary urine filtration in the renal corpuscles is made possible by the high blood pressure in the glomerular capillaries. A sharp drop in blood pressure leads to decreased urinary excretion.

The urine eliminated from the organism is called secondary or final urine. It is formed from the primary urine in the uriniferous tubules of the nephron by *reabsorption* into the blood of water and some of the substances dissolved in the water. It has been calculated that almost 100 litres of primary urine is formed in 24 hours, but only about 1.5 litres of secondary urine is excreted. Primary urine differs in composition from secondary urine in that it contains glucose, amino acids and certain other substances. As the primary urine flows through the tubules of the nephrons, all these substances, as well as the greater part of the water, are reabsorbed into the blood circulating in the blood capillaries of the uriniferous tubules, which are branches of efferent vessels.

Secondary urine passes from the nephrons into the collecting tubules and thence into the minor calyces. The minor calyces (there are 8 to 12 in each kidney) open out into 2 or 3 major calyces which then lead to the renal pelvis. The urine passes from the pelvis through a ureter into the urinary bladder.

One of the most important functions of the kidneys is to keep the concentration of salt constant in the blood. Various salts and certain other substances are eliminated from the blood in the urine, the rate of elimination varying with the processes operating in the organism. For example, during gastric digestion the chlorine ions contained in the blood plasma are intensively used by the gastric glands to form hydrochloric acid, and elimination of these ions in the urine decreases accordingly. When an excess of salts is delivered to the blood their elimination in the urine increases. The concentration of salts in the blood plasma is thereby maintained at a constant level. At the same time the osmotic pressure and a definite acid-base balance are maintained relatively constant in all tissues of the organism.

**Regulation of urine formation.** The work of the kidneys is subject to regulation by the nervous system and to humoral regulation. The kidneys contain a large number of nerve fibres. Nerve impulses transmitted along nerve fibres from the central nervous system cause the renal blood vessels to become constricted or dilated, and the permeability of the glomerular walls and the absorptive capacity of the epithelial cells of the uriniferous tubules are altered. This affects the process of urine formation. For example, when the renal blood vessels are constricted, the inflow of blood diminishes, and so less urine is formed. Increased permeability of the glomerular walls or diminished absorptive capacity of the cells of uriniferous tubules is accompanied by increased urine formation and even a change in the composition of the urine.

K. Bykov demonstrated connections between the cerebral cortex and the kidneys by experiments with conditioned reflexes. Administration of water into an animal's organism was combined with the action of another stimulus, for example, metronome beats. The water naturally caused urine formation to increase. After several administrations the metronome beats alone (without the water) brought about increased urinary output. This was because a conditioned reflex had been built up. It has also been shown that the renal vessels, like the vessels of other internal organs, contain sensory nerve endings which, when stimulated, will reflexly alter cardiovascular and respiratory activity.

Of the humoral factors which influence urine formation the most important is the part played by hormones. For example, one of the hormones produced by the anterior lobe of the hypophysis (diuretic hormone) stimulates urine formation. The posterior lobe of the hypophysis produces an antidiuretic hormone which increases the reabsorption into the blood of the water present in the uriniferous tubules and thus causes a decrease in the amount of final urine. When there is a temporary excess of water in the organism the action of the antidiuretic hormone ceases and urine formation increases; when there is



Plate III. Microscopic structure of kidney (diagram). Left: cortical (I) and medullary (II) layers. Right: greatly magnified glomerulus with capsule and beginning of uriniferous tubule

1—capsule with glomerulus; 2, 3, and 4—different parts of uriniferous tubule; 5—collecting tubules through which urine passes into minor calyx; 6—artery; 7—vessel bringing blood to glomerulus; 8—vessel removing blood from glomerulus; 9—capillaries enveloping tubules; 10—vein



a deficiency of water the action of this hormone increases and the amount of urine decreases, but the urine becomes more concentrated. Some people suffer from hypofunctioning of the posterior lobe of the hypophysis, which leads to decreased secretion of the antidiuretic hormone. In such cases the process of reabsorption in the uriniferous tubules is disturbed and a large amount of urine is excreted (diabetes insipidus).

Urine formation is also affected by other hormones (thyroxin—hormone of the thyroid gland, adrenalin—hormone of the adrenals, etc.). For example, thyroxin reduces the reabsorption of water in the uriniferous tubules, which leads to diuresis. Adrenalin constricts the afferent vessels of the glomeruli. As a result, the pressure in the glomeruli drops, which leads to decreased filtration and a decrease in urinary output.

Products of protein decomposition (urea, etc.) also influence renal activity by causing diuresis.

The influence of humoral factors on the process of urine formation has been demonstrated by transplantation of kidneys in animals with severance of direct connections between this organ and the nervous system. The transplanted kidney begins to secrete urine immediately its blood circulation is restored.

Medical practice makes wide use of so-called diuretics (diuretin, etc.).

### *Urine*

Urine is a straw-yellow weakly-acid fluid. Man excretes an average of about 1.5 litres of urine in 24 hours. The specific gravity of urine is slightly higher than that of water (above unity) and is 1.015-1.020\*.

**Composition of urine.** The urine consists of water and organic substances dissolved in it. The urine of a healthy person (normal urine) contains about 95 per cent water and 5 per cent other substances. The organic substances eliminated in the urine are mainly products of protein decomposition. They include urea, uric acid, creatinine, hippuric acid, etc. Most of them contain nitrogen (nitrogen-containing substances). The inorganic constituents of urine are common salt, salts of sulphuric and phosphoric acids, potassium oxide, etc.

The daily portion of urine contains a total of about 60 g of organic and inorganic substances. The substances excreted in the urine in greatest amounts are urea (25-30 g) and common salt (10-15 g). About nine-tenths of the nitrogen contained in the products of protein decomposition are excreted from the organism in the urea. A constant composition of salts is maintained in the blood by the excretion of common salt and other salts through the kidneys.

\* 1 litre of water weighs 1,000 g and 1 litre of urine weighs 1,015-1,020 g.



Besides the above-mentioned substances the urine of a healthy person may also contain gases (carbon dioxide, etc.), single leucocytes and desquamated epithelial cells of the urinary tract.

The *amount*, *composition* and *properties* of urine vary considerably, depending on the temperature and humidity of the surrounding environment, the type of work, amount and composition of food, amount of ingested water, etc. The amount of urine decreases when a man sweats profusely, eats dry or desiccated food, drinks a limited amount of water, etc. The output of urine increases in cold and humid weather and when liquid food and large amounts of water are consumed. Urine is usually excreted more intensively during the day than at night. The amount of urine and its specific gravity alter simultaneously. If the amount of urine decreases its specific gravity usually increases and, vice versa, as the urinary output increases its specific gravity decreases. The specific gravity of urine may vary between 1.002 and 1.030. It is determined by a special instrument—a *uro-meter*.

The colour of the urine may also change in intensity. It depends on the quantities of special pigments (urobilin, urochrome) present in the urine and formed from bile pigments. It should be noted that the colour of urine may also change in disease (jaundice, haemorrhages in the kidneys, ureters, etc.) and after intake of certain drugs.

The reaction of the urine is affected by the composition of the food. If a vegetable diet is followed for a long time the reaction may be not weakly-acid, as when the diet consists of mixed food, but alkaline.

All changes in metabolism, and various dysfunctions of the kidneys, affect the composition of urine. As a rule, the urine of every patient is examined. Some diseases cause characteristic changes in the composition of urine. For example, the urine of a healthy person contains no proteins, sugar or blood, whereas the urine of sick people ("pathologic" urine) may contain them.

The presence of proteins in the urine is called *albuminuria*. Prolonged albuminuria is a sign of renal disease accompanied by increased permeability of the blood capillaries of the kidneys. Protein may temporarily appear in the urine during very strenuous physical work. The presence of sugar in the urine is called *glycosuria*. Prolonged glycosuria is a sign of diabetes mellitus. This disease develops when the pancreas does not secrete enough of its hormone—insulin (see "Endocrine Glands"). Sugar may appear temporarily in the urine if a large amount of carbohydrates is ingested.

The presence of blood in the urine is called *haematuria*. Haematuria may vary in degree from a small number of erythrocytes discoverable only under the microscope to an admixture of blood seen by the naked eye. Haematuria indicates affection of the renal glomeruli or a haemorrhage in the urinary tract.

In pathologic urine there may also be casts (cells of renal epithelium) sticking together in columns, microbes, a large number of leucocytes, etc.

Sometimes renal calculi form in the urinary tract, usually in the renal pelvis, from the salts present in the urine. Renal calculi may cause attacks of acute pain in the region of the kidneys (renal colic).

### *Ureter*

A ureter is a tube about 30 cm long (see Fig. 86). After leaving the hilus renalis a ureter descends along the posterior abdominal wall into the cavity of the true pelvis where it perforates the wall of the bladder and opens into its cavity. The wall of a ureter consists of three coats; one *mucous*, one *muscular* and a *connective-tissue coat (adventitia)*. The mucous coat is lined with stratified epithelium. The muscular coat consists of circular and longitudinal layers of smooth muscle tissue. The muscular coat of the ureter contracts and performs peristaltic movements.

### *Bladder*

The bladder (*vesica urinaria*) is a reservoir for urine (Fig. 88). It is situated in the cavity of the true pelvis at the back of the symphysis pubis. Between the symphysis pubis and the bladder there is a layer of loose cellular tissue. In males the rectum is behind the bladder and in females, the uterus and part of the vagina.

The bladder has three parts; the superior part or *apex*, the middle part or *body*, and the inferior part or *fundus*. The wall of the bladder consists of three coatings—mucous, muscular and connective-tissue. On top, on part of the sides and at the back the bladder is additionally covered by serous membrane, called the *peritoneum*. The mucous membrane of the bladder forms numerous folds which are absent only in the region of the fundus where there is a smooth triangular area, the trigone or vesical triangle, between the orifices of the two ureters and the internal urethral orifice. As the bladder fills up the folds of the mucous coat straighten out.

The muscular coat consists of three layers of smooth muscles extending in different directions.

The capacity of the bladder of an adult averages 350-500 ml. When the bladder is too full its apex rises the superior border of the symphysis pubis and contacts the anterior abdominal wall.

The structure of the urethra is described below (pp. 185 and 191).

they constitute the *seminal fluid*.\* From the seminiferous tubules the sperm is delivered to the mediastinum testis and thence along 10 to 12 efferent ductules to the *duct of the epididymis*. The testis of the foetus is situated in the abdominal cavity and descends through

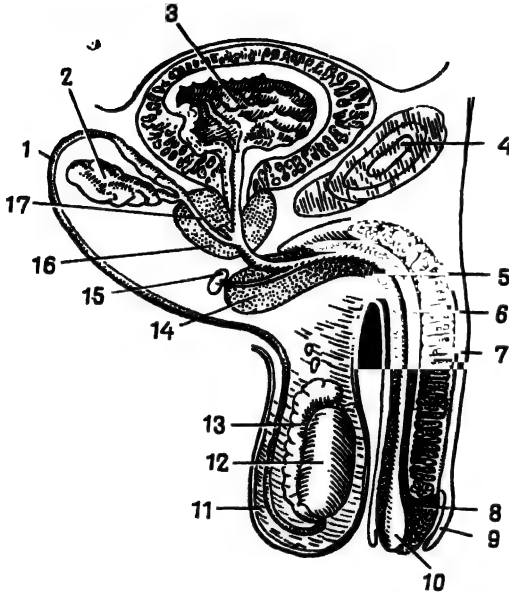


Fig. 89. Section of male genitalia (diagram)  
 1—deferent duct; 2—seminal vesicle; 3—cavity of bladder; 4—symphysis pubis; 5—urethra; 6—corpus cavernosum urethrae; 7—corpus cavernosum penis; 8—glans penis; 9—prepuce; 10—urethral dilation (navicular fossa); 11—scrotum; 12—testis; 13—epididymis; 14—bulb of corpus cavernosum urethrae; 15—bulbo-urethral (Cowper's) gland; 16—prostate gland; 17—ejaculatory duct

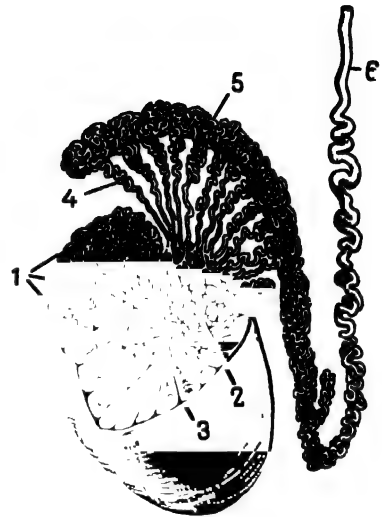


Fig. 90. Testis. The tunica albuginea testis is partly opened  
 1—lobules of testis; 2—rete testis; 3—tunica albuginea; 4—efferent ductule; 5—epididymal duct; 6—deferent duct

the inguinal canal into the scrotum. By the time of birth both testes are usually in the scrotum.

The *epididymis* (see Fig. 90) is a small body lying close to the posterior border of the seminal gland. It has a duct which is continuous with the deferent duct.

The *deferent duct* (see Fig. 89) has the shape of a tube which is about 40 to 50 cm long and serves to transmit the seminal fluid. Its wall consists of three coats—mucous, muscular and connective-

\* The seminal fluid discharged in sexual intercourse through the urethra includes the secretion of the prostate and of the seminal vesicles.

tissue. It rises from the inferior end of the epididymis and enters the inguinal canal through its subcutaneous ring. In the inguinal canal the deferent duct runs in the spermatic cord.

**Spermatic cord.** The spermatic cord is the thickness of the little finger and consists, besides the deferent duct, of the nerves, blood and lymph vessels of the testis, and of the epididymis; they are surrounded by a common fascial membrane. At the deep ring of the inguinal canal the deferent duct separates from the vessels and nerves and descends into the cavity of the true pelvis, to the fundus of the bladder, whereas the blood and lymph vessels and nerves ascend towards the abdominal cavity. Near the prostate the deferent duct joins the excretory duct of the seminal vesicle, thus forming the *ejaculatory duct*.

**Seminal vesicle.** The seminal vesicle (see Fig. 89) is a paired organ of elongated form and is about 4 to 5 cm long; it is located between the fundus of the bladder and the rectum. The seminal vesicles are reservoirs for the seminal fluid. They also produce a secretion which is a constituent of this fluid.

**Ejaculatory duct.** The ejaculatory duct (see Fig. 89) is formed, as mentioned above, by junction of the deferent duct and the duct of the seminal vesicle. It passes through the substance of the prostate and opens into the prostatic part of the urethra. Close to 200 million spermatozoa are discharged at each ejaculation.

**The prostate.** It is situated in the cavity of the true pelvis under the fundus of the bladder (see Fig. 89) and has a base and an apex. The base of the gland is directed upward and is fused with the fundus of the bladder; the apex is directed downward and adheres to the urogenital diaphragm. The gland is composed of muscular (smooth) and glandular tissue. The glandular tissue forms lobes whose ducts open into the prostatic part of the urethra. The secretion of the gland is a constituent of the seminal fluid. By contracting the muscular tissue of the gland helps to empty the ducts and simultaneously performs the function of a urethral sphincter. As mentioned above, the prostate gives passage to the urethra and the two ejaculatory ducts. In advanced life the gland sometimes becomes enlarged because of an increase in its connective tissue and it may interfere with the emptying of the urinary bladder. The prostate and seminal vesicles may be palpated through the rectum.

The *bulbo-urethral* or *Cowper's glands* (see Fig. 89) are a paired organ situated in the urogenital diaphragm. Each gland is the penile portion of the urethra.

### *External Male Genitalia*

The *scrotum* is a cutaneous sac holding the testes and their epididymides (see Fig. 89).

Under the skin of the scrotum is the so-called *dartos* which consists of connective tissue and a large number of smooth muscle fibres. Under the dartos is a fascia which covers the *cremaster* muscle. This muscle is composed of striated muscle tissue and when it contracts it elevates the testes. Under the muscle are the *tunica vaginalis communis* and the *tunica vaginalis propria testis*. The former is a process of the endo-abdominal fascia and covers the testis and the spermatic cord. The latter is a serous membrane. In the process of development the peritoneum forms a projection into the scrotum (vaginal process) which gives rise to the *tunica vaginalis propria testis*. It consists of two layers with a slit-like cavity in between and contains a small amount of serous fluid. One of the layers covers the testis and the other adheres to the *tunica vaginalis communis*.

**The penis.** It has a *glans*, a *body* and a *root* (see Fig. 89). The glans is the thickened distal end. The urethra opens at the tip of the glans. Between the glans and the body is a narrow portion called the neck. The root is attached to the pubic bones.

The penis consists of three so-called *corpora cavernosa* (cavernous bodies). Two of them are *corpora cavernosa* of the penis and one is the *corpus cavernosum* of the urethra (it transmits the urethra). The distal end of the *corpus cavernosum urethrae* is thickened and forms the glans penis. Each *corpus cavernosum* is covered with a dense connective-tissue coat and is of a spongy structure; the numerous connective-tissue septa form small cavities called caverns. During sexual excitement these caverns fill with blood, and the penis becomes turgid and erect. The penis is covered with skin which forms a fold, the *prepuce* (foreskin), on the glans.

The male urethra serves not only for voiding the urine from the bladder, but also for ejaculating the seminal fluid. It is 16 to 18 cm long and passes through the prostate, the urogenital diaphragm and the *corpus cavernosum* in the penis. It is accordingly considered in three portions: *prostatic*, *membranous* and *spongy* or *penile* (Fig. 89).

The *prostatic* portion is the widest. It is about 3 cm long. There is a swelling on its posterior wall—the *seminal colliculus*. On it open the two ejaculatory ducts, through which the seminal fluid is transmitted from the seminal glands, and the ducts of the prostate gland, whose secretion is a constituent of the seminal fluid.

The *membranous* portion is the narrowest and shortest (about 1 cm long); it is firmly fused with the urogenital diaphragm.

The *spongy* or *penile* portion is the longest (12 to 14 cm long); it ends in the external orifice of the urethra in the glans penis. The posterior part of the spongy portion is dilated and is called the *bulbous part* of the urethra. The ducts of Cowper's glands open in this part. The secretion of these glands is a constituent of the seminal fluid. The distal part of the spongy portion immediately behind the

external urethral orifice is also dilated and is called the *navicular fossa*. There are small depressions on the mucous coat of the spongy portion, called *lacunas*.

The male urethra has two *sphincters*—internal and external. The internal sphincter contracts involuntary (it is composed of smooth muscle tissue); it surrounds the urethra at the site where it leaves the bladder. The external sphincter is in the urogenital diaphragm round the membranous portion of the urethra; it contracts voluntarily (it is composed of striated muscle tissue).

The male urethra has two *curves*, the *prepubic* and *subpubic* curves (see Fig. 89). The prepubic curve is permanent; the subpubic curve straightens out upon erection of the penis. The structure and position of the male urethra (dilations and constrictions, curves, etc.) must be taken into account when a catheter is being introduced into the bladder.

## FEMALE GENITALIA

### • Internal Female Genitalia

An *ovary* (ovarium) (Fig. 91) is one of a pair of organs. It is a sexual gland in which female germ cells develop and mature, and female sex hormones are produced. The ovaries are located in the cavity of the true pelvis laterally of the uterus. Each ovary is an oval and somewhat flattened body weighing about 5 to 6 g. An ovary has anterior and posterior borders and superior and inferior ends. The anterior border is fused with the broad ligament of the uterus, while the posterior border is free. The superior end is turned towards the uterine tube, and the inferior end is connected with the uterus by means of the proper ligament of the ovary. The ovary is covered by a membrane composed of connective tissue and epithelium.

A section of the ovary shows medullary and cortical substance. The medullary substance consists of loose connective tissue which transmits blood vessels and nerves. The framework of the cortical substance is also formed of loose connective tissue. A large number of follicles are imbedded in the cortical layer and form the *parenchyma* of the ovary. Each *follicle* (Fig. 92) is sac-shaped and contains a female germ cell. The walls of the sac are made up of epithelial cells. In a sexually mature female the follicles are all at different stages of development and of different sizes. The ovary of a newborn girl contains from 40,000 to 200,000 so-called primary, immature follicles. Maturation of follicles begins at sexual maturity (12-16 years of age). However, not more than 500 follicles mature in a woman's lifetime; the rest of them dissolve. As a follicle matures the cells which compose its wall proliferate and the follicle enlarges.

ges; a cavity filled with fluid forms inside. A mature follicle, which is about 2 mm in diameter, is called a *graafian follicle*. A follicle takes about 28 days, or one lunar month, to mature. The ovum present in the follicle develops as the follicle matures, undergoing complex changes. The development of the female germ cell in the ovary is called *oogenesis*.

The wall of a mature follicle thins out and ruptures. The ovum

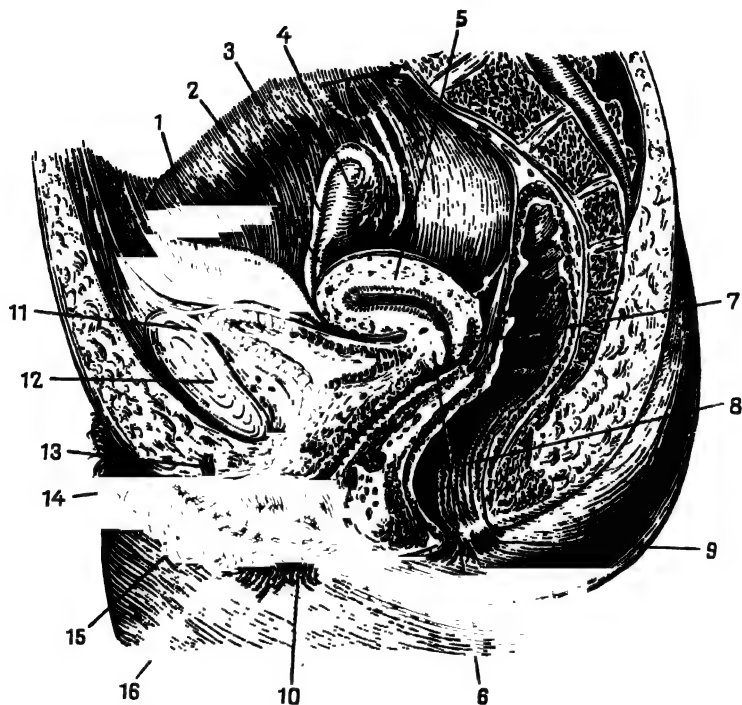


Fig. 91. Sagittal section of female pelvis

1—round ligament of uterus; 2—proper ligament of ovary; 3—uterine tube; 4—ovary; 5—uterus; 6—anterior lip of cervix uteri; 7—posterior lip of cervix uteri; 8—rectum; 9—anus; 10—vaginal orifice; 11—bladder; 12—symphysis pubis; 13—clitoris; 14—external urethral orifice; 15—labium majus; 16—labium minus

present in the follicle is carried away by the flow of fluid into the peritoneal cavity, and it enters the uterine tube (oviduct).

The maturation of the female germ cell in the follicle of the ovary and its leaving the graafian follicle is called *ovulation*. A *corpus luteum* (yellow body) forms at the site of the ruptured graafian fol-

le. If pregnancy occurs, the corpus luteum persists till the end of it and performs the function of an endocrine gland (see Chapter 12, "Endocrine Glands"). If no fertilization occurs, the corpus luteum atrophies, leaving a scar. Ovulation is intimately connected with *menstruation*, a periodic discharge of a sanguineous fluid from the

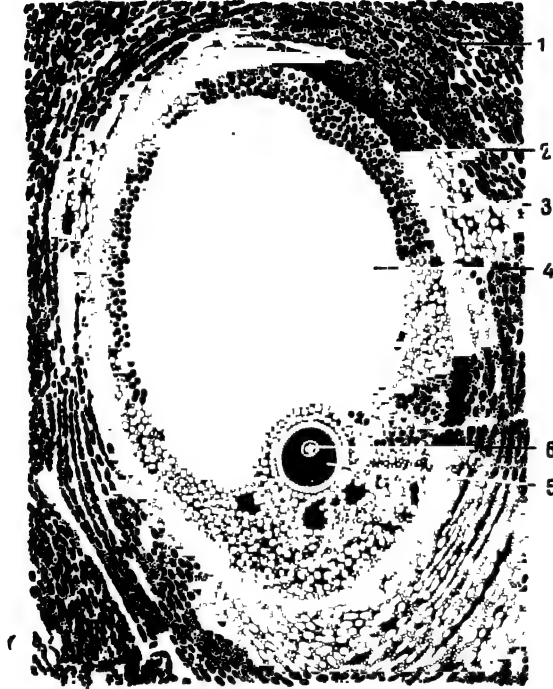


Fig. 92. Graafian follicle in the ovary

1—substance of the ovary; 2—membranes of graafian follicle; 3—cells of graafian follicle;  
4—cavity of graafian follicle filled with fluid; 5—ovum; 6—nucleus of ovum

uterus (see "Uterus" below). During pregnancy both ovulation and menstruation cease.

Ovulation and menstruation are observed from the age of 12-16 to 45-50, after which the woman has the so-called *menopause*. At this time ovarian function and menstruation cease.

The *uterine tubes* or salpinges (Fig. 93) are a paired organ; they are located laterally of the uterus, in the upper part of its broad ligament, and carry ova from the ovary to the uterus. The wall of a uterine tube is composed of a mucous coat, a muscular layer and a serous covering. The mucous coat is lined with ciliated epithelium.



The muscular layer consists of smooth muscle tissue. The peritoneum is the serous covering. A uterine tube has two orifices; one of them opens into the uterine cavity, while the other opens into the peritoneal cavity, near the ovary. The end of a uterine tube, which communicates with an ovary, is dilated in the form of a funnel and terminates in fringes called *fimbriae*. After leaving the ovary ova reach the uterine tube along these fimbriae. The union of an ovum and spermatozoon in a uterine tube results in *fertilization*. The fertili-

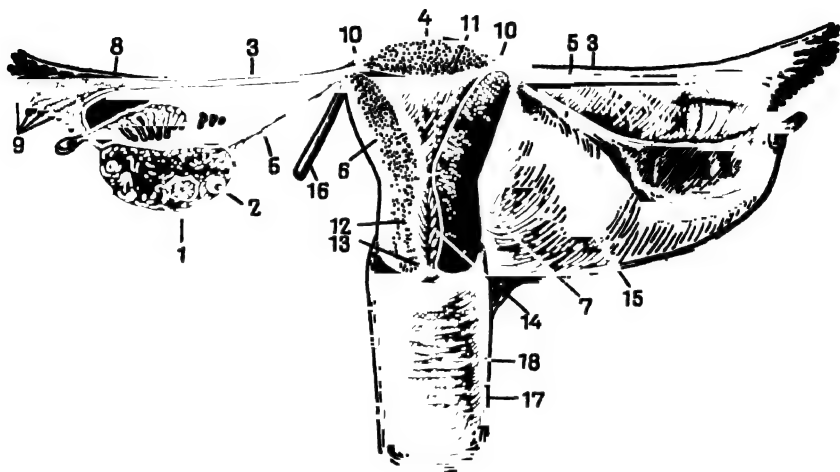


Fig. 93. Female internal genitalia (posterior aspect). Uterus, vagina, left ovary and tube (section)

1—ovary; 2—graafian follicle; 3—uterine tube; 4—fundus uteri; 5—proper ligament of ovary; 6—body of uterus; 7—cervix uteri; 8—orifice of uterine tube opening into peritoneal cavity; 9—fimbriae; 10—orifice of uterine tube opening into uterine cavity; 11—uterine cavity; 12—cervical canal; 13—os uteri externum; 14—folds of mucosa in cervical canal; 15—broad ligament of uterus; 16—round ligament of uterus; 17—vagina; 18—folds of vaginal mucosa

zed ovum begins to divide and an *embryo* develops. The developing embryo moves along the uterine tube to the uterus. The vibrations of the cilia of the ciliated epithelium and the contractions of the wall of the uterine tube apparently help the embryo in its movement.

The *uterus* (in Greek—*metra*) is a muscular organ of gestation (see Fig. 93). It is located in the cavity of the true pelvis behind the bladder and in front of the rectum. The organ is pear-shaped. Its upper and broad portion is called the *fundus*, its middle portion is the *body*, and the lower portion is the *cervix*. The constricted part between the body and the cervix is known as the *isthmus*. The cervix communicates with the vagina. The body is bent forward on the cervix;

this bend is called the *anteflexion*. Inside the body is a slit-like cavity which is continuous with the *cervical canal*; the junction is often called the *os uteri internum*. The cervical canal opens into the vagina, through the opening known as the *os uteri externum*. The latter is bounded by two thickenings called the *anterior* and *posterior lips* of the cervix of the uterus. The orifices of the two uterine tubes open into the cavity of the uterus.

The *wall* of the uterus is composed of three coats: the inner, middle and outer coats.

The *inner* coat is called the *endometrium*. It is a mucous membrane lined with columnar epithelium. It has a smooth surface in the uterine cavity and small folds in the canal of the cervix. Glands secreting into the cavity of the uterus are imbedded in the mucous membrane. At sexual maturity the mucous membrane of the uterus undergoes periodic changes which are intimately connected with the processes operating in the ovaries (ovulation and formation of the corpus luteum). At the time a developing embryo should enter the uterus from a uterine tube the mucous membrane enlarges and swells. The embryo implants itself in this loosened mucous membrane. However, if the ovum is not fertilized the greater part of the mucous membrane of the uterus is cast off. The blood vessels rupture and a uterine haemorrhage, *menstruation*, takes place. Menstruation lasts for 3 to 5 days, after which the mucous membrane of the uterus is restored and the entire cycle of changes is repeated. Such changes occur every 28 days.

The *middle* coat is the strongest and consists of smooth muscle tissue. It is called the *myometrium*. Its muscle fibres run in different directions. During parturition the contractions of the muscular coat of the uterus expel the foetus from the uterus into the vagina and thence to the exterior.

The *outer* coat is called the *perimetrium*; it is a serous covering—the peritoneum. The peritoneum covers the entire uterus except for the part of the cervix which communicates with the vagina. It extends from the uterus to the other organs and walls of the true pelvis, forming two peritoneum-lined pouches in the cavity of the true pelvis. The *vesico-uterine pouch* lies in front of the uterus and the *recto-uterine pouch* lies behind the uterus. The posterior pouch is the larger of the two.

Surrounding the uterus, between the layers of the broad ligament of the uterus, is an accumulation of adipose tissue called the *parametrium*.

The uterus is a motile organ. When the bladder fills the uterus is displaced backwards, and when the rectum fills it is displaced forwards. However, the motility of the uterus is limited by the uterine ligaments which help to fix it in place.

**Ligaments of the uterus.** There are broad, round and uterosacral ligaments. All ligaments of the uterus are paired. The *broad* ligaments are folds of the two layers of the peritoneum extending from the uterus to the lateral walls of the true pelvis. In the upper part of the broad ligaments are the uterine tubes. The *round* ligaments are cord-shaped; they are composed of connective tissue and smooth muscle fibres. They extend from the uterus to the deep ring of the inguinal canal, run through the canal and end in the labia majora. The *uterosacral* ligaments are bundles of connective-tissue fibres extending from the uterus to the rectum and thence to the sacrum. The muscles of the pelvic floor (see "Perineum") play an important part in reinforcing the uterus and other organs of the true pelvis.

The position, size and structure of the uterus change during pregnancy. As the foetus grows the gravid uterus gradually enlarges, its walls becoming somewhat thinner. Towards the end of pregnancy the fundus uteri reaches a level halfway between the xiphoid process and the navel. The mucous membrane of the uterus undergoes considerable changes in connection with the development of the foetal membranes and placenta (see "Outline of the Development of the Human Foetus"). The muscular coating of the uterus enlarges because of the growth of the muscle fibres both in length and in girth. As a result, the weight of the uterus increases almost 20-fold. The period of gestation lasts about 280 days (10 lunar months). After delivery the uterus quickly diminishes in size and resumes its former position. The uterus of a woman who has never borne a child weighs about 50 g, and that of a woman who has borne children weighs about 100 g. Doctors examine the uterus manually and the cervix visually. A visual examination is performed through the vagina, and a manual examination through the vagina or rectum.

The *vagina* is a tube about 8 to 10 cm long (see Fig. 91). During copulation the seminal fluid containing spermatozoa is discharged from the penis into the vagina. The spermatozoa are motile, and swim from the vagina into the uterine cavity and thence into the uterine tubes. During parturition the foetus passes from the uterus out of the body through the vagina. The walls of the vagina are composed of three coats—one mucous, one muscular and one of connective-tissue. The mucous coat forms folds on the anterior and posterior walls of the vagina. The upper part of the vagina is fused with the cervix uteri forming vaults, the *fornices* of the vagina, between the walls of the vagina and the cervix. There are two fornices of the vagina: anterior and posterior. The lower part of the vagina opens into the vestibule of the vagina. In front of the vagina is the fundus of the bladder and the urethra, and behind it is the rectum. The vagina communicates with the peritoneal cavity through the uterus and uterine tubes.

### External Female Genitalia\*

The *labia majora* are two folds of skin containing a large amount of adipose tissue. They bound the space called the *rima pudendi*. The posterior and anterior ends of the labia majora are joined by small folds of skin: the posterior and anterior commissures. Above the labia majora, over the symphysis pubis, is the *mons veneris*. Here the skin is plentifully covered with hair and contains a large amount of adipose tissue.

The *labia minora* are also two folds of skin. The narrow opening between the labia minora is called the *vestibule* of the vagina. The external orifice of the urethra and the entrance to the vagina open into the vestibule of the vagina. In girls the entrance to the vagina is blocked by a band of mucous membrane, called the *maidenhead* or *hymen*. During the first copulation the hymen is ruptured and a little blood is discharged because of the injury to blood vessels. Two large *vestibular glands* (*Bartholin's glands*) are imbedded at the base of the labia minora; the ducts of these glands open on the surface of the labia minora in the vestibule of the vagina.

The *clitoris* is situated in the vestibule of the vagina to the front of the external orifice of the urethra. It is a small fingerlike eminence and consists of two cavernous bodies which in structure are similar to those of the penis; the clitoris contains a large number of sensory nerve endings whose stimulation evokes sexual excitement.

### Female Urethra

The female urethra is almost rectilinear (see Fig. 91). It is 3 to 3.5 cm long, wider than the male urethra and is easily distensible. It is lined with a mucous membrane in which are imbedded a large number of mucus-secreting glands. It originates in the fundus of the bladder (internal orifice), passes through the urogenital diaphragm in front of the vagina and opens into the vestibule of the vagina (external orifice). Like the male urethra, the female urethra has two sphincters, one internal and one external.

### Perineum

The perineum is the portion of the body included in the outlet of the true pelvis and situated between the pubic arch and the coccyx. The external genitalia and the anus are in this region. Under the skin of the perineum are adipose tissue, and then the muscles and fasciae which form the pelvic floor. The pelvic floor has two parts: the pelvic diaphragm and the urogenital diaphragm.

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\* The visible external female genitalia are called the vulva.

The *pelvic diaphragm* consists of two paired muscles called the levator ani and the coccygeus (Fig. 94). The muscles are covered with fasciae above and below. The terminal part of the rectum, which ends in the anus, passes through the pelvic diaphragm. The anus is surrounded by a muscle which is its external sphincter. On each

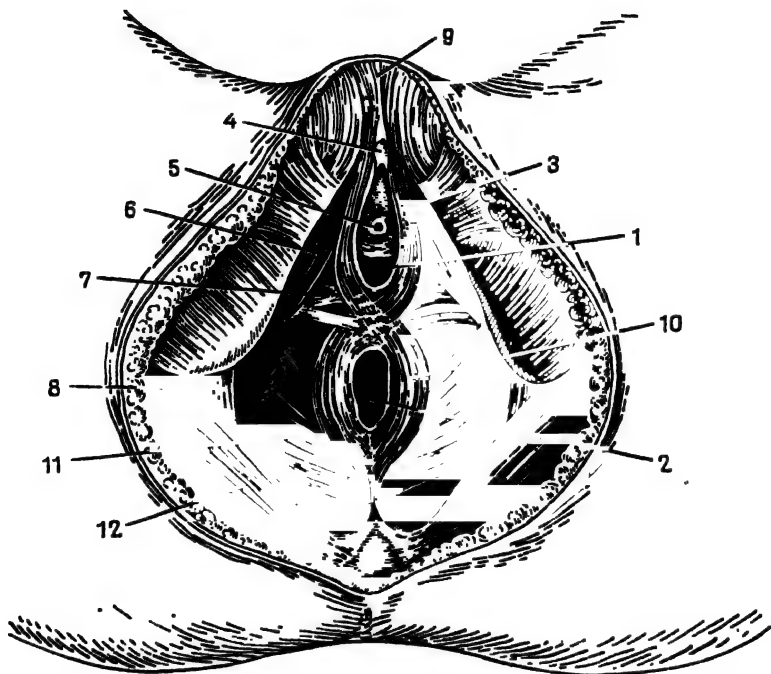


Fig. 94. Muscles of pelvic floor in female (view from below)

1—vaginal orifice; 2—anus; 3—bulbocavernosus muscle; 4—clitoris; 5—external urethral orifice; 6—ischio-cavernosus muscle; 7—transversus perinei profundus muscle; 8—sacro-tuberous ligament; 9—mons veneris; 10—sphincter ani externus; 11—levator ani; 12—gluteus maximus muscle

side between the inferior portion of the rectum and the ischial tuberosity is a recess, called the ischio-rectal fossa. It is filled with adipose tissue, blood vessels and nerves.

The *urogenital diaphragm* is the anterior portion of the pelvic floor and is situated between the pubic bones. It is formed by a paired muscle (the transversus perinei profundus) and is covered with fasciae on both sides. In males the urethra passes through the urogenital diaphragm, and in females through the urethra and the va-

gina. The muscle forming the external sphincter of the urethra is imbedded in the urogenital diaphragm.

All the muscles of the perineum are striated.

In obstetrics the term perineum implies that portion of the pelvic floor which is situated between the external genitalia and the anus.

### OUTLINE OF THE DEVELOPMENT OF THE HUMAN FOETUS

The tissues and organs of the human body form and develop during the embryonic and foetal stages. The embryonic stage begins with fertilization and ends in the third month of pregnancy. The foetal stage lasts from the end of the third month until birth. Fertilization is the act of impregnation, when the male and female gametes fuse. The *male gametes* (spermatozoa, reproductive cells) have a lash-like appearance and consist of a head with a perforatorium, a neck, and a tail (Fig. 95). They are motile, due to the movements of their tails. The *female gamete* (ovum) is spherical and many times larger than a spermatozoon. The mature ovum, as mentioned above (p. 187), finds its way into the uterine tubes from the ovary. The union of the male and female gametes in the initial part of a uterine tube results in fertilization which is the beginning of pregnancy.

As it moves along the uterine tube to the uterus the fertilized ovum divides into daughter cells, called blastomeres. This division is called *cleavage*. During the period of cleavage the embryo is nourished by the nutrients present in the ovum. The process of cleavage ends on about the 5th or 6th day of pregnancy, and by this time the embryo has entered the cavity of the uterus and assumed the form of a vesicle, a *blastocyst*, with a fluid-filled cavity (Fig. 96). The wall of a human blastocyst consists of one layer of cells; this layer is known as the *trophoblast* and is the bud of the embryonic (foetal) membranes. Under the trophoblast lies a small clump of cells from which the embryo proper will later develop. This clump of cells is called the *embryoblast*.

On the 6th or 7th day of pregnancy the embryo implants itself in the mucous coat of the uterus. During the two following weeks

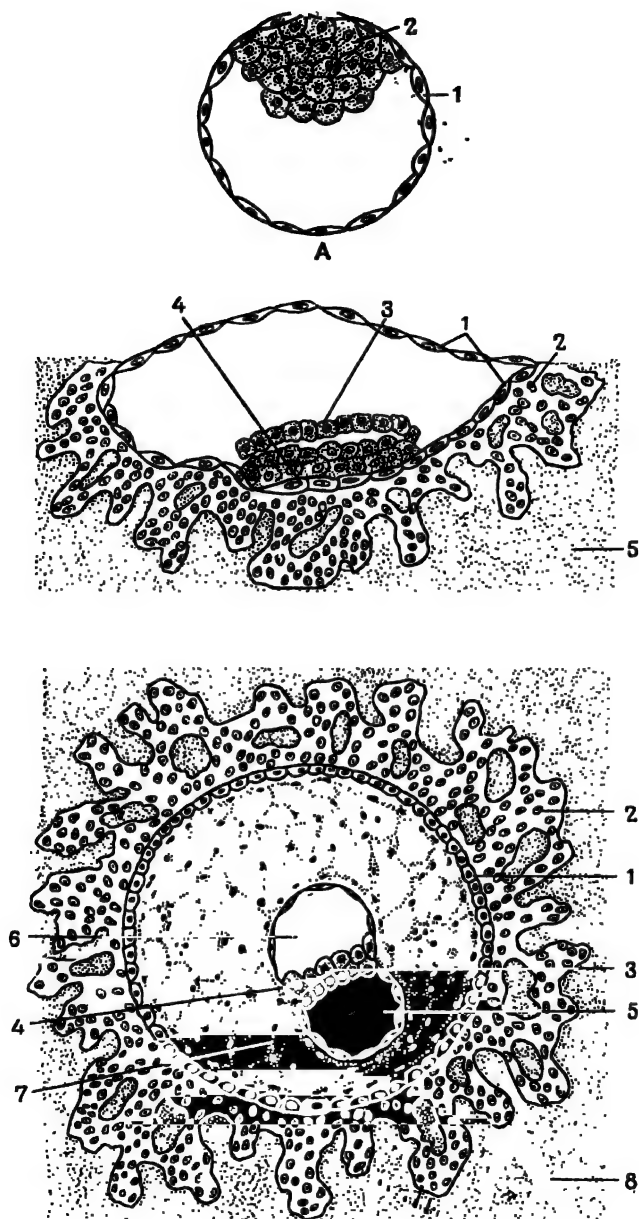


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A B

Fig. 95. Human spermatozoon (diagram)

A—view from above; B—lateral view; 1—head; 2—neck; 3—tail; 4—perforatorium



**Fig. 96. Early stages of development of the human embryo**

*A*—blastocyst; 1—trophoblast; 2—embryoblast; *B*—seven-day-old embryo; 1 and 2—trophoblast; 3—entoderm; 4—ectoderm; 5—uterine mucosa; *C*—eleven-day-old embryo; 1 and 2—chorion; 3—ectoderm; 4—entoderm; 5—amniotic vesicle; 6—yolk sac; 7—mesenchyme; 8—uterine mucosa

(i.e., up to the end of the 3rd week after fertilization) *gastrulation* takes place. This is the formation of germ disks and the subsequent deposition of the buds of different organs. At the same time the so-called *extraembryonic parts*, i.e., the *yolk sac*, *allantois*, *embryonic (foetal) membranes* and other structures, develop. In gastrulation



Fig. 97. Derivatives of the three germ layers  
I—entoderm; II—mesoderm; III—ectoderm

the embryoblast divides (splits) into two disks or primary germ layers—the *ectoderm* (outermost) and the *entoderm* (innermost) (Fig. 96). The entoderm in its turn gives rise to the *mesoderm* (middle germ layer).

In the process of gastrulation the primary germ layers, particularly the mesoderm, give rise to cells which fill the spaces between the germ layers. The aggregate of these cells is called the *mesenchyme*.



By a series of complex transformations (differentiation) and growth the primary germ layers develop into all the tissues and organs (Fig. 97). The ectoderm develops into the epithelium of the skin and the mucosa of the oral and nasal cavities, the nervous system and part of the sense organs.

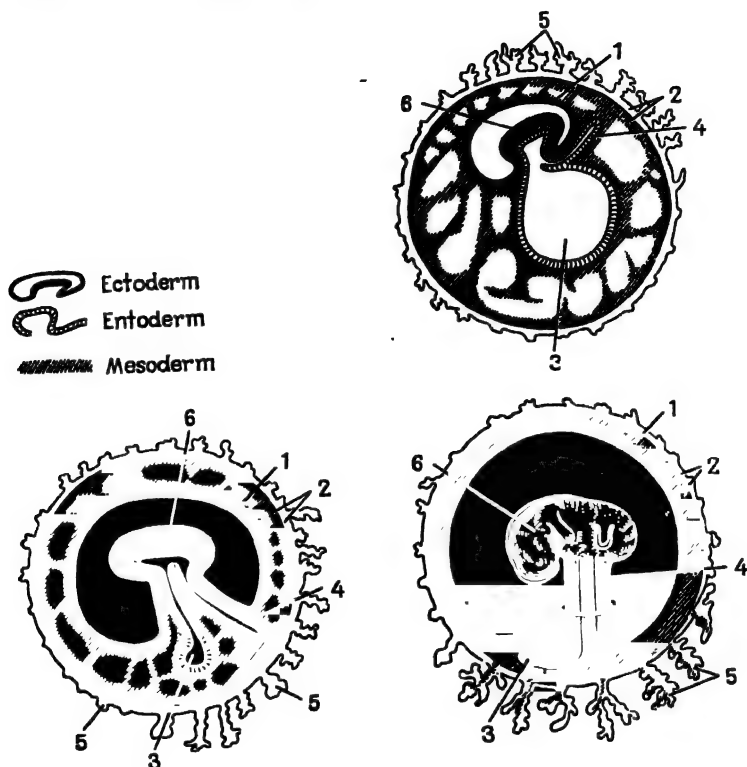


Fig. 98. Development of embryo and extra-embryonic parts

1—amnion; 2—chorion; 3—yolk sac; 4—allantois; 5—chorionic villi; 6—embryo

The entoderm gives rise to the epithelium of the mucosa of the digestive tract (except the oral cavity), to digestive glands, the epithelium of the respiratory organs (except the nasal cavity) and to the thyroid, parathyroid and thymus glands.

The mesoderm produces the skeletal musculature, part of the urinary organs, the sex glands and the epithelium (mesothelium) of the serous membranes.

The connective tissues, vascular system and haematopoietic organs develop from the mesenchyme.

The extra-embryonic parts play an important role in the development of the embryo. The *yolk sac* (Fig. 98) functions in the early stages of embryonic life. It takes part in nourishing the embryo during the period of implantation in the wall of the uterus. During this period the embryo is nourished by the products of decomposition of the uterine mucosa. The nutrients are assimilated by the cells of the trophoblast, whence they pass into the yolk sac and thence

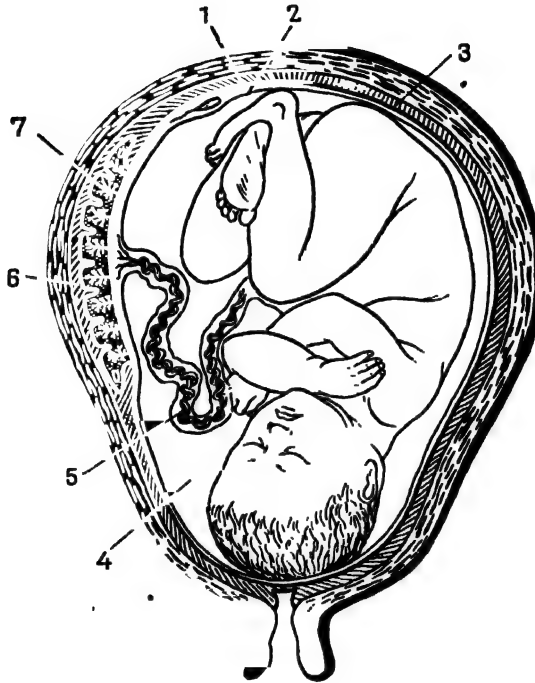


Fig. 99. Position of foetal membranes in the uterus

1—chorion; 2—amnion; 3—decidual membrane; 4—cavity of amnion filled with amniotic fluid; 5—umbilical cord; 6—maternal part of placenta; 7—foetal part of placenta

to the embryo. For a short time the yolk sac performs a haematopoietic function (it gives rise to blood cells and vessels) and then it atrophies.

The *allantois* (see Fig. 98) plays an important part in the development of the embryo of birds and reptiles, particularly in ensuring respiration and excretion. The role of the allantois in man is limited to linking the blood vessels of the embryo and its villous membrane, the *chorion*. The umbilical blood vessels develop in the wall of the allantois. They communicate with the vessels of the embryo and

grow into the part of the chorion which participates in the formation of the placenta.

**Embryonic (foetal) membranes.** Three membranes—the amnion, chorion and decidual membrane—form around the embryo (Fig. 99).

The *amnion* is the membrane closest to the embryo (foetus). It forms a closed sac and contains the embryo (foetus) and the *amniotic fluid*. The amniotic fluid is produced by the amnion. Towards the end of pregnancy the fluid amounts to around 1 to 1.5 litres.



Fig. 100. Structure of human placenta (section)

1—amnion; 2—chorion; 3—chorionic villi; 4—lacunas; 5—uterine mucosa (basal plate); 6—muscular coat of uterus

It protects the embryo from harmful influences and allows development and movement.

The *chorion* is the outermost of the embryonic membranes. It develops from the trophoblast of the embryo and from the adjoining part of the mesenchyme. At first the entire chorion is covered by so-called *primary villi*. Later the primary villi disappear from almost the entire surface of the chorion and are replaced by *secondary villi* covering only a small portion of it. This part of the chorion participates in formation of the placenta. The amnion and chorion are embryonic membranes; they are derived from the fertilized ovum.

The *decidual membrane* lies outside the chorion. It is a maternal membrane because it is formed from the uterine mucosa. The greater portion of the decidual membrane is a thin layer. A small part of this membrane, called the basal plate, is thickened and forms part of the placenta. The decidual membrane, like the embryonic (foetal) membranes and the placenta, is cast off during parturition and is expelled from the uterus after the foetus. The *placenta* is a

disk-shaped organ, 20 to 30 cm in diameter and 2 to 3 cm thick (Fig. 100). It consists of two parts—one foetal and one maternal. Between the two are the lacunas or chambers in which the maternal blood circulates. The foetal and maternal parts of the placenta are joined by connective tissue.

The foetal part of the placenta is the part of the chorion with villi. Each villus of the chorion divides into many branches and resembles a tree; the villi contain vessels which are branchings of the umbilical vessels (arteries and vein). The villi grow into the part of the decidual membrane which is called the basal plate. Then the basal plate is partly destroyed. The maternal part of the placenta is a small layer of connective tissue which is preserved after the destruction of the basal plate of the uterine mucosa.

From the end of the third week and up to the end of pregnancy the foetus receives nutrients and oxygen from the maternal organism through the placenta and gives off the products of metabolism. A continuous interchange of substances takes place between the maternal blood circulating in the lacunas and the foetal blood flowing through the vessels of the villi. The maternal and foetal blood does not mix.

Rapid development of the organs occurs with the transition to the placental and most perfect form of intrauterine nutrition. It is precisely during this period that the foetus grows intensively in length and weight.

The placenta communicates with the foetus through the umbilical cord which is about 50 cm long and 1.5 cm thick. The umbilical cord carries two umbilical arteries and one umbilical vein (see "Blood Circulation in the Foetus").

After the establishment of placental nutrition the body of the foetus is formed as follows.

During the fourth week the embryo detaches itself from the extra-embryonic parts and, because of its rapid growth in length, it becomes spirally twisted. Arm and leg buds appear in the form of small tubercles.

By the end of the sixth week the embryo has grown to be 2 cm long\*. The buds of the extremities are larger and fingers can already be observed; the head develops considerably and the tail grows much longer. The face begins to form, and the upper and lower jaws can be distinguished; the external ear also begins to develop. At this age a definite eminence can be seen in the cervical region; this contains buds of the heart and kidneys.

At the age of eight weeks the embryo is human in appearance. It is 4 cm long and weighs 4 to 5 g. The cerebral hemispheres are developing and the head of the embryo takes on a human form with

\* The length is measured from the coccyx to the bregma.

the main facial features—nose, ears, eyesockets—outlined. The cervical region can be seen and also developing digits, especially the fingers. By the end of the eighth week the rudiments of all organs have been formed. It is now usually called a foetus.

A 3-month-old foetus is human in appearance except for its comparatively large head. The face is well formed. The head and neck have straightened out. Lip movements characteristic of the sucking reflex appear. The extremities are well developed and contract in response to stimulation. Other organs also begin their functions. The 3-month-old foetus is about 8 cm long and weighs 45 g. Subsequently the weight and length of the foetus rapidly increase. Gestation in women lasts about 10 lunar months (280 days). By the end of pregnancy the foetus is about 50 cm long and weighs about 3.5 kg.

## *Blood. Cardiovascular System*

### BLOOD

The blood is a red fluid of alkaline reaction and is salty in taste; its specific gravity is 1.050-1.060. The body of an adult contains about five litres of blood which weigh one thirteenth of the total body weight.

The blood and lymph constitute the internal environment of the organism and have a large number of functions.

#### *Functions of the Blood*

The blood performs an important function in *metabolism*; it delivers nutrients to the tissues of all the organs and carries the waste products away. Nutrients are absorbed into the blood from the small intestine. The waste products are eliminated from the blood through the excretory organs.

The blood performs a most important function in *respiration*; it delivers oxygen to the tissues of the organs and carries carbon dioxide away. Oxygen enters the blood through the lungs. Carbon dioxide is eliminated from the blood mainly through the lungs.

The blood effects *humoral regulation of the activities* of various organs; it transports various substances (hormones, etc.) round the organism. Some of these substances stimulate, while others inhibit the work of the organs.

The blood also has a *protective function*; it contains cells which possess properties of phagocytosis, and special products called *antibodies*, which play a protective role.

The blood takes part in distributing heat within the organism and in maintaining a constant body temperature. Because of the movement of blood through the blood vessels heat is transported from

warmer parts of the body to cooled parts. The blood gives off the excess of heat into the external environment, and the organism therefore does not become overheated.

The amount and composition of the blood in a healthy person are relatively constant; they are subject to slight variations depending on the external conditions of the organism, but quickly return to normal. Various diseases cause considerable changes in the blood. The character of these changes may help in diagnosing the disease, and so a complete medical examination necessarily involves a blood test. If all tissues of the organism are to function normally the amount and composition of the blood must be relatively constant.

It should be noted that part of the blood does not circulate through the blood vessels, but is stored in so-called blood depots (in the capillaries of the spleen, liver and subcutaneous tissue). Under different conditions the volume of blood circulating in the organism may increase or decrease through a change in the volume of depot blood. For example, during muscular work and in cases of blood loss the blood from the depots is released into general circulation.

The total amount of blood may temporarily increase after the intake of a large amount of fluid and absorption of water from the intestines. However, the excess of water is comparatively quickly eliminated from a healthy organism through the kidneys. A temporary decrease in the amount of blood is observed in cases of bleeding. A rapid loss of a large amount of blood (one-third to half of the total volume) may prove fatal.

### *Composition of the Blood*

The blood consists of cells or formed elements and plasma. The cells make up 40-45 per cent of the total amount of blood and the plasma makes up 55-60 per cent.

### *Cellular Elements of the Blood*

The cellular elements of the blood consist of erythrocytes, leucocytes and blood platelets or thrombocytes (Plate IV).

The blood of a healthy person contains 4,500,000-5,000,000 *erythrocytes*, or red blood cells, per 1 cu mm. Erythrocytes are cells without nuclei which resemble biconcave disks. They are 7-8  $\mu$  in diameter and 1.5-2  $\mu$  thick. The cytoplasm of erythrocytes contains a protein pigment, *haemoglobin*, which is responsible for the red colour of the blood. Iron is one of the constituents of a haemoglobin. The most important function of erythrocytes is that they carry oxygen. When the blood flows through the lungs the haemoglobin in the erythrocytes absorbs oxygen and then the oxygenated (arterial) blo-

od is transported throughout the organism. In the organs oxygen is dissociated from the haemoglobin and enters the tissues. Haemoglobin also participates in the transportation of carbon dioxide from the tissues to the lungs where it passes out of the blood and into the air. Most of the carbon dioxide is carried away by the blood plasma.

The absolute oxygen content in a human adult averages 12.5-14 per cent of the weight of the blood, but may reach 17 per cent (17 g of haemoglobin in 100 g of blood). Blood tests usually determine the relative haemoglobin content, which expresses in per cent the ratio of the actual amount of haemoglobin in 100 g of blood to 17 g and varies between 70 and 100 per cent.

In some pathologic conditions the haemoglobin content of the blood changes. For example, the main sign of anaemia is a decrease in haemoglobin content; in this condition either the number of erythrocytes or the haemoglobin content in them (or both) may be reduced.

*Leucocytes* or white blood cells number 6,000-9,000 per 1 cu mm of blood in a healthy man. Leucocytes have nuclei and vary in size. They are actively motile and in virtue of this their shape changes. The cytoplasm of some leucocytes contains granules; the cytoplasm of others does not. All leucocytes are divided into those which are granular and those which are nongranular.

*Granular leucocytes*, or *granulocytes*, are 9-12  $\mu$  in diameter. Their nuclei usually consist of segments interconnected by filaments (*segmented leucocytes*). Younger forms of granular leucocytes with band-shaped nuclei (*band cells*) occur less frequently, and oval nuclei (*juvenile cells*) occur very rarely.

The granular leucocytes are not all alike. There are three types which are distinguished according to their staining reaction (acid or basic dyes): eosinophils, basophils and neutrophils. The cytoplasm of *eosinophils* contains large granules of equal size, which stain an intense pink or red. *Basophils* have granules of different sizes which stain blue. *Neutrophils* contain fine, dust-like granules which stain a light-violet with both acid and basic dyes.

*Nongranular leucocytes*, or *agranulocytes*, have no granules in their cytoplasm.

There are two types of these cells: lymphocytes and monocytes. *Lymphocytes* are small cells (6.5-8.5  $\mu$  in diameter) with a round nucleus surrounded by a thin rim of cytoplasm. *Monocytes* are larger cells (12-20  $\mu$  in diameter) with a bean-shaped or, less frequently, an oval nucleus.

The correlation between the different types of granular and nongranular leucocytes in the blood of a healthy man is comparatively constant and is known as the leucocyte count; it is expressed in per cent in Table 3.



Table 3

## Correlation Between Different Types of Leucocytes (in %)

Granular leucocytes					Nongranular leucocytes	
Neutrophils			Eosino- phils	Basophils	Lympho- cytes	Mono- cytes
Juvenile	Band cells	Segmented cells				
Up to 1	3-4	60-70	2-4	0.5-1	20-25	6-8

Many diseases are characterized by a change in the total number of leucocytes, and in the correlation between the different types of cells. Most diseases involve an increase in the number of white blood cells. This phenomenon is called *leucocytosis*. However, some diseases are accompanied by a decrease in the number of leucocytes; this condition is known as *leucopenia*. The correlations between the groups of leucocytes change differently in different diseases. For example, in some diseases the percentage of eosinophils increases (this condition is called *eosinophilia*), while other diseases are characterized by an increase in neutrophils (*neutrophilia*), etc. Eosinophilia is observed particularly in helminthiasis and scarlet fever.

Temporary changes in the number of leucocytes may also occur in a healthy person. For example, leucocytosis is observed after meals and during physical work.

Leucocytes perform a protective function. They have the property of *phagocytosis* (Fig. 101), i.e., they engulf and destroy bacteria and other organic particles, and are capable of passing through the walls of vessels and of moving through tissues to the site of inflammation. There are facts indicating that leucocytes discharge enzymes and other substances into the blood plasma, which help to fight the infectious agents which have entered the organism. The protective role of leucocytes was discovered and the theory of phagocytosis was originated, as mentioned above, by the great Russian scientist Ivan Mechnikov (1845-1916).

*Blood platelets*, or *thrombocytes*, are very small (2-3  $\mu$ ) irregularly-shaped structures. They contain *thrombokinas*, a substance which participates in blood clotting. The number of thrombocytes is not constant and varies between 100,000 and 300,000 per 1 cu mm of blood. A sharp decrease in the number of thrombocytes is called *thrombopenia*. In thrombopenia the ability of the blood to clot is impaired.

### Blood Plasma

The plasma is a viscous, slightly yellowish, protein fluid. In it are suspended the cellular elements of the blood. It consists of 90-92 per cent water and 8-10 per cent organic and inorganic substances. The greater part of the organic substances are blood proteins, albumin, globulin and fibrinogen. The plasma also contains glucose, fat, fatlike substances, amino acids, various metabolites (urea, uric acid, etc.), enzymes and hormones. Inorganic substances make up about 0.9-1 per cent of the blood plasma and include the salts of



Fig. 101. Phagocytosis of a bacterium by a leucocyte. Three successive stages (diagram)

sodium, potassium, calcium, etc. The concentration of different salts in the plasma is relatively constant. Mineral substances, especially sodium chloride, play the main part in keeping the osmotic pressure of the blood relatively constant. The blood plasma is closely linked with the tissue fluids of the organism; it provides the tissues with all the substances necessary for their vital processes and receives their metabolites from them. In a healthy man the osmotic pressure is relatively constant in all tissues. Any sizeable change in the osmotic pressure in the tissues disturbs their activities. The composition of the blood plasma is very important for maintaining the chemical reaction of the blood (pH) relatively constant.

The blood plasma, as mentioned above, contains special substances, called *antibodies*, which play a protective role. Some of them



Ilya Mechnikov .

are able to neutralize toxins (poisons liberated by bacteria), others destroy the bacteria which have entered the organism, and still others agglutinate them, etc. Antibodies may persist for a long time in the blood of a person who has survived a disease, so that he is no longer susceptible to that particular disease.

Many diseases may be prevented by producing insusceptibility artificially; a vaccine containing a small number of killed or attenuated (weakened) bacteria and their toxins is introduced into the organism. The organism produces antibodies in response to this. Inoculations against smallpox, typhoid fever and other diseases are examples of the administration of such vaccines. Insusceptibility to disease is called *immunity*.

In some diseases patients are administered therapeutic sera. Serum is the blood plasma deprived of fibrinogen. Therapeutic sera contain antibodies and are prepared from the blood of animals that have survived that particular disease.

## GENERAL PROPERTIES OF THE BLOOD

*Blood Clotting*

The blood possesses the ability to clot. Normally when the blood flows through the blood vessels it does not clot. In some diseases, however, blood clots form within blood vessels and obstruct them. These clots are called *thrombi* (the singular is *thrombus*).

The blood usually clots after escaping from the blood vessels. The clotting process involves *fibrinogen* (protein), *thrombogen* or *prothrombin* (a special enzyme), *thrombokinase* (an enzyme present in blood platelets), calcium salts and certain other substances. Prothrombin is formed in the liver with the participation of vitamin K and is delivered to the blood plasma. Human blood also contains an enzyme which prevents blood clotting—*antithrombin* (heparin). This enzyme is produced in the liver and lungs and is also delivered to the blood plasma.

The following gives an outline of blood coagulation. During bleeding the blood platelets are destroyed as soon as they come into contact with the air. At the same time they liberate thrombokinase. In the presence of calcium salts and certain other substances thrombokinase converts the inactive thrombogen into active thrombin. Fibrinogen, which is dissolved in the plasma, changes under the action of thrombin into a dense substance called *fibrin*, with the result that a blood clot is formed. The clot consists of intertwined filaments of fibrin and formed elements of the blood.

Human blood escaping from the organism clots within 3 to 4 minutes. Heat accelerates blood clotting, and cold sharply slows it down.

To prevent blood from clotting, citric acid or its salts are added to the blood (*citrated blood*), addition of oxalic acid or its salts produces *oxalated blood*. These substances precipitate the calcium salts from the plasma. Such blood can be preserved for a long time, and is used for transfusions.

Blood clotting is also prevented by *hirudin*, a substance produced by the buccal glands of leeches.

A disease known as *haemophilia* is often observed in males; in this disease the blood will not clot and the slightest wound is accompanied by profuse bleeding.

*Erythrocyte Sedimentation Test*

Doctors often use the so-called erythrocyte sedimentation test. This test is based on the fact that if blood is allowed to stand in a vessel the erythrocytes, which have a higher specific gravity than

the plasma, settle to the bottom. As a result, two layers of blood are formed; an upper layer containing clear plasma, and a lower layer composed of erythrocytes. The test is performed as follows: a little blood taken from a finger is mixed with a sodium citrate solution and is aspirated into a glass capillary tube in a special piece of apparatus. The tube is fixed absolutely vertically in a test-tube rack. The erythrocytes gradually settle to the bottom. The height of the column of blood without erythrocytes is measured in millimetres within an hour. The normal sedimentation rate of erythrocytes is 4-10 mm/hour. In many diseases the erythrocyte sedimentation rate (ESR) rises because of changes in the physicochemical properties of the blood. A faster ESR is usually a sign of a current or past disease. The ESR is also faster in pregnancy.

### Blood Groups

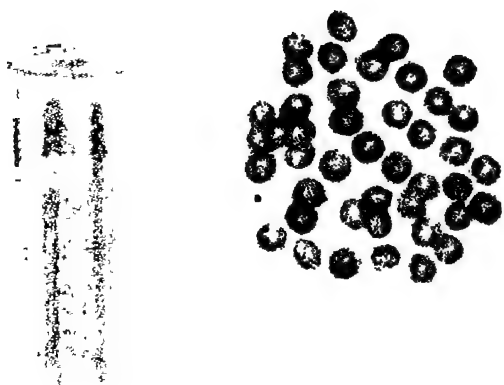
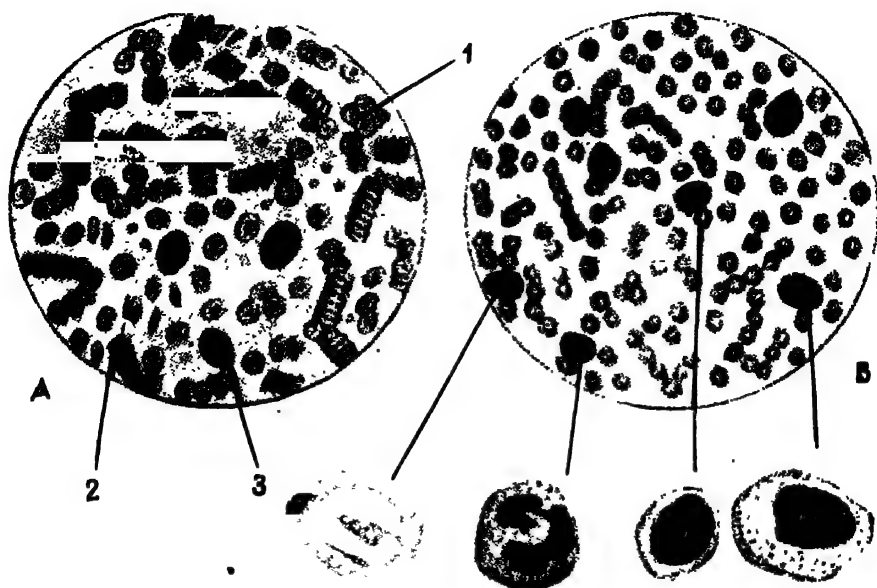
Doctors often give blood transfusions (for loss of blood due to injury, to certain debilitated patients, etc.). People who give their blood for transfusion are called *donors*; those who receive blood transfusions are called *recipients*. Before administering a blood transfusion it is necessary to consider *agglutination*, the property of erythrocytes to gather into clumps under certain conditions. Agglutination of erythrocytes in human blood leads to severe disturbances and may cause death.

The blood of different people differs in its content of certain special substances called *agglutinins* (causing agglutination) and *agglutinogens* (causing production of agglutinins). Agglutinins are present in the blood plasma, and agglutinogens in the erythrocytes. There are two types of agglutinins and they are designated by the Greek letters  $\alpha$  and  $\beta$ . There are also two types of agglutinogens: A and B. The blood of different people contains different agglutinins and agglutinogens.

In accordance with this four blood groups are distinguished: first (I), second (II), third (III) and fourth (IV). The groups are characterized as follows (Table 4).

Table 4

Blood Groups		
Group	Agglutinins in the plasma	Agglutinogens in the erythrocytes
First group (I, 0) . . . . .	$\alpha, \beta$	Absent
Second group (II, A) . . . . .	$\beta$	A
Third group (III, B) . . . . .	$\alpha$	B
Fourth group (IV, AB) . . . . .	Absent	AB



#### Plate IV. Blood

*A*—blood seen under microscope, *1* and *2*—erythrocytes; *3*—leucocyte. *B*—stained blood preparation (below—various types of leucocytes, greatly magnified). *C*—erythrocytes. *D*—blood safeguarded against clotting after prolonged sedimentation; upper layer—plasma (erythrocytes have settled out)

■

■

Erythrocytes will agglutinate only if, when the two types of blood are mixed, agglutinin A of the donor's blood encounters agglutinin  $\alpha$  of the recipient's blood or if agglutinin B of the donor's blood meets with agglutinin  $\beta$  of the recipient's blood. Consequently, when the bloods are mixed, only the agglutinogens of the donor's blood and the agglutinins of the recipient's blood are taken into consideration, since only the donor's erythrocytes are subject to agglutination.

Those groups of blood which, when mixed, produce agglutination

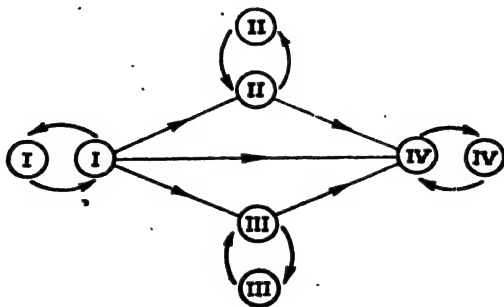


Fig. 102. Diagram of blood group compatibility. Arrows show which groups of blood may be transfused to which

are called *incompatible*, while those which produce no agglutination are called *compatible*. Fig. 102 is a diagram showing compatible blood groups.

Fig. 102 shows that group I blood may be transfused to people with any blood group, whereas people with group I blood may be transfused blood only of the same group.

People with group IV blood may be transfused blood of any group, but their blood may be transfused only to people with blood of the same group. People with group I blood are called *universal donors* and people with group IV blood are called *universal recipients*.

Blood of groups II and III may be transfused to people with blood of the same group or group IV blood. People with blood of groups II and III may receive blood of the same groups or of group I.

It has lately been established that blood contains also other agglutinogens (in addition to A and B). The erythrocytes of most people have an agglutinin named the *Rh factor* (first found in the rhesus monkey). Such people are called *Rh positive*. The minority of people with no such agglutinin in the blood are known as *Rh negative*. In some cases the donor's blood is incompatible with the recipient's



blood in the Rh factor (although it is of the same group). Transfusion of such blood is very dangerous because it results in destruction of the erythrocytes of the transfused blood. At the same time the haemoglobin escapes into the blood plasma. This phenomenon (escape of haemoglobin into the plasma) is called *haemolysis*. Completely haemolysed blood retains its red colour, but becomes transparent and is referred to as *laky blood*.

The blood group of the patient (the recipient) must always be determined before a transfusion. The blood for transfusion is chosen on the basis of a blood group test. Moreover, a so-called *biological test* is also performed. This test consists in giving at first only a small amount of blood (75 ml in doses of 25 ml at 3-minute intervals) and watching the patient's condition. If untoward phenomena (chills, tachycardia, and in graver cases constriction in the chest, pain in the small of the back, etc.) are observed, the blood transfusion is discontinued.

Blood transfusion is widely used and is a most important medical procedure.

### *Haematopoietic Organs*

Throughout the life of an organism blood cells age and die, and new blood is produced. The production of new blood is called *haematopoiesis*. The organs in which blood cells are produced are the *red marrow*, the *lymph nodes* and the *spleen* (in the foetus blood is also produced in the liver).

In adults *red marrow* is located in the interstices of the spongy substance of short and flat bones and the epiphyses of long bones. In foetuses and newborn children it also fills the canals of tubular bones where it is gradually replaced by yellow marrow which takes no part in haematopoiesis. The basis of red bone marrow is reticular tissue which has an abundant supply of blood vessels. Red marrow has special cells from which formed elements of the blood develop. These cells reproduce continuously; some of them are transformed by a series of complex processes into erythrocytes and granular leucocytes which pass into the blood. The total volume of red marrow in the human body is 1,500 cc.

The *lymph nodes* are organs in which lymphocytes develop. They also perform a protective function (see p. 245).

The *spleen* (lien) is located in the left hypochondrium immediately below the diaphragm (Fig. 103). Normally the spleen is not palpable, but in some diseases it enlarges and projects from under the ribs. Anterior and posterior borders and two surfaces are distinguished. One surface is convex and faces the diaphragm, while the other surface is concave and is in contact with the fundus of the stomach, the left kidney and the tail of the pancreas. The concave surface has

a *hilus* which transmits vessels and nerves. The spleen is covered by the peritoneum; under the serous covering there is a connective-tissue capsule. Connective-tissue partitions, called *trabeculae*, radiate from the capsule into the organ. Between the trabeculae is the so-called *splenic pulp*, which is dark-red. The base of the pulp is compo-

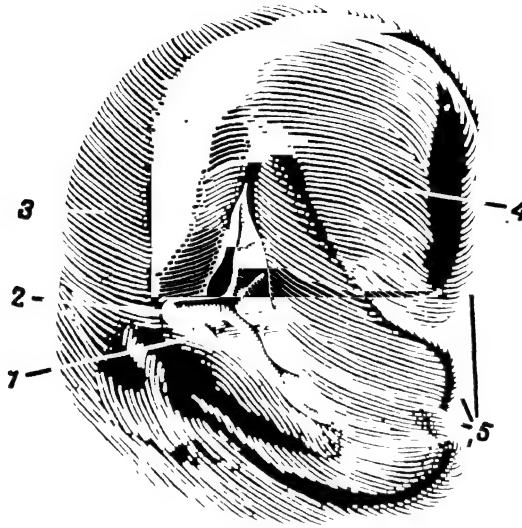


Fig. 103. Spleen

1—splenic vein; 2—splenic artery; 3—site of contact with left kidney; 4—site of contact with stomach; 5—anterior border of spleen

sed of reticular tissue with an abundant supply of blood vessels. The pulp has lighter-coloured islets of lymphoid tissue in which lymphocytes develop. Besides participating in haematopoiesis the spleen also performs other functions. Aged erythrocytes are destroyed in the spleen. Moreover, a considerable amount of blood may accumulate temporarily in the spleen, as it does in the liver and the subcutaneous vascular network. Such organs are called *blood depots*.

## CARDIOVASCULAR SYSTEM

### General Information

The blood continuously moves through the organism; this movement is called *blood circulation*. All organs of the human body communicate with each other through the circulation of the blood. It

supplies them with nutrients and oxygen; removes waste products, and ensures that humoral regulation is effected and other vital functions of the organism performed. If the blood stops circulating the organism dies.

The blood flows through blood vessels, which are elastic tubes with varying diameters. A closed network of blood vessels radiates throughout the entire body. The *heart*, which is a hollow, muscular organ, contracts rhythmically and pumps the blood throughout the organism.

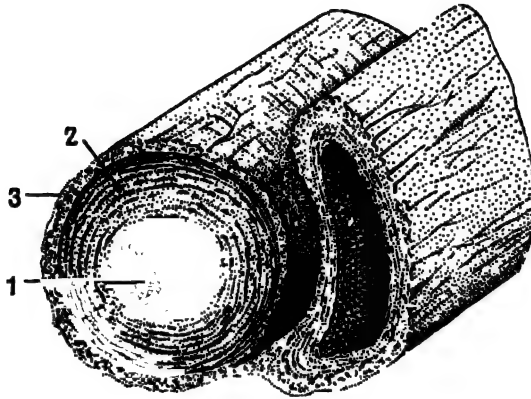


Fig. 104. Structure of artery and adjacent vein  
1—tunica intima; 2—tunica media; 3—tunica adventitia

The discovery of the mechanism of blood circulation is connected with the name of the English scientist William Harvey (1578-1657).

The activity of the cardiovascular system is regulated by the nervous system. The work of the heart and blood vessels is also influenced by hormones and other substances. The theory of regulation of the blood circulation was elaborated mainly by I. Pavlov and other Russian scientists.

### *Blood Vessels*

There are three types of blood vessels—arteries, capillaries and veins. They differ from each other in structure and in function.

**Arteries** are vessels through which the blood flows from the heart to organs. They have comparatively thick walls made up of three coats: an outer coat, a middle coat and an inner coat (Fig. 104). The outer coat, or *tunica adventitia*, consists of connective tissue. The middle coat, or *tunica media*, consists of smooth muscle tissue and contains elastic connective-tissue fibres. Contractions of this coat

decrease the lumen of the blood vessel. The inner coating, or *tunica intima*, is made up of connective tissue and is lined with a layer of flat cells, the endothelium. The arteries differ in diameter; the farther from the heart, the smaller the diameter. Inside each organ the artery divides into smaller branches. The smallest arterial vessels are called arterioles. The arterioles divide into capillaries.

**Capillaries** are minute blood vessels which are visible only under the microscope. The lumens of the capillaries vary and average  $7.5\ \mu$ ; the length of a capillary does not exceed 0.3 mm. There are several hundred capillaries per square millimetre of tissue of any organ. The total lumen of the capillaries of the entire body is 500 times that of the aorta. When an organ is in a state of rest most of its capillaries are contracted and no blood flows through them. In an active organ the number of functioning capillaries increases. The wall of a capillary consists of one layer of endothelial cells. The interchange of substances between the blood and the tissues takes place only through the capillary walls. Various nutrients and oxygen, and part of the blood plasma of which lymph is formed, pass from the blood into the tissues. Carbon dioxide and other waste products pass from the tissues into the blood. The endothelium of the capillaries plays an active role in allowing the substances to pass from the blood into the tissues and vice versa. The interchange of substances depends not only on the state of the capillary walls, but also on the main substance of the connective tissue surrounding the capillaries. As it flows through a capillary arterial blood changes to venous blood, which drains into the veins.

**Veins** are vessels through which blood flows from the organs to the heart. Like arteries, they have walls composed of three coats (Fig. 104), but they contain fewer elastic and muscle fibres and so are less resilient and collapse easily.

Unlike arteries, veins have valves (see Fig. 116) which open in the direction of the blood flow. This helps the blood in the veins to flow in the direction of the heart.

The smallest veins are called *venules*. Closer to the heart the venous vessels increase in diameter. The total lumen of the veins is larger than that of the arteries, but smaller than that of the capillaries.

Each region or organ of the body is usually supplied with blood by several vessels. One of them, the largest in diameter, is called the main vessel, while the smaller ones are called the accessory or collateral vessels. Some arteries communicate with each other through connecting vessels, called **anastomoses**. There are also anastomoses between veins.

If the blood ceases to flow in one vessel (if the vessel is cut or compressed by a tumour, etc.) the circulation through the collateral vessels and anastomoses will increase. New collateral vessels and anasto-

moses may gradually develop in addition to the existing ones. The blood circulation is thus restored.

### Heart

**Structure of the heart.** The heart (*cor*) is a hollow, muscular, cone-shaped organ located in the anterior mediastinum (Fig. 105). The

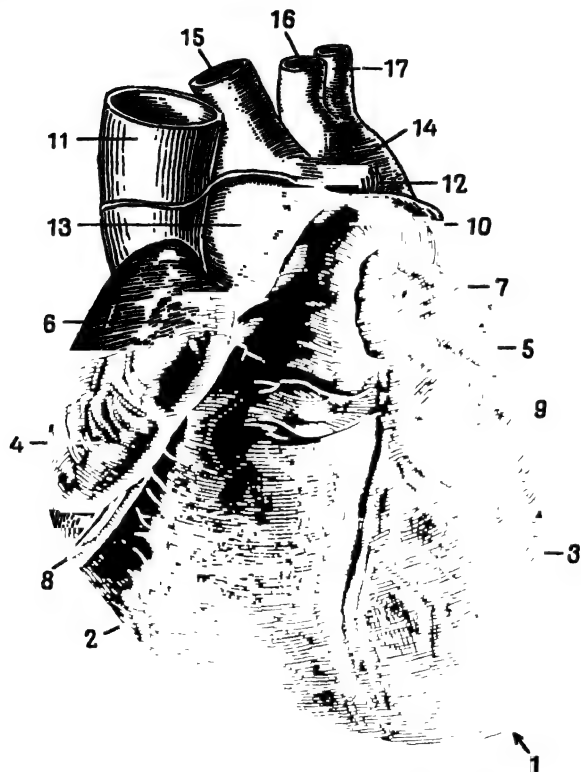


Fig. 105. Heart. Anterior view

1—apex; 2—right ventricle; 3—left ventricle; 4—right atrium; 5—left atrium; 6—right auricle; 7—left auricle; 8—coronary sulcus; 9—anterior longitudinal sulcus; 10—pulmonary trunk; 11—superior vena cava; 12—ligamentum arteriosum (closed Botallo's duct); 13—aorta; 14—point where pericardium becomes endocardium; 15—brachiocephalic trunk (innominate artery); 16—left common carotid artery; 17—left subclavian artery

greater part of the heart is situated in the left half of the thoracic cavity. The heart is about the size of the person's fist and weighs about 300 g. The parts of the heart are the broad part or *base*, the constricted part or *apex*, and the *anterior*, *posterior* and *inferior surfaces*.

The base of the heart is directed upward and backward, and the apex downward and forward; the anterior surface faces the sternum and costal cartilages, the posterior faces the oesophagus, and the inferior faces the tendinous centre of the diaphragm.

The wall of the heart consists of three coats: *inner* or *endocardium*, *middle* or *myocardium*, and *outer* or *epicardium*. The entire heart is enveloped in a membranous sac called the *pericardium*. The pericardium and epicardium are the two layers of the serous coat of the heart; between them is a slit-like space, the *pericardial cavity*, which contains a small amount of serous fluid. The myocardium, the most powerful coat of the heart wall, consists of striated muscle tissue. The muscle fibres of the heart wall are interconnected by trabeculae (anastomoses). Unlike skeletal muscles the heart muscle, although striated, contracts involuntarily.

The endocardium is a thin connective-tissue membrane lined with endothelium. It lines the heart muscle and forms the heart valves.

The human heart has four chambers (Fig. 106). A longitudinal partition divides it into right and left halves, which do not communicate\*. Venous blood flows through the right half and arterial blood through the left. Each half of the heart consists of two chambers, the upper called the *atrium* and the lower called the *ventricle*, which communicate with each other through the *atrioventricular* (AV) *orifice*. The wall of each atrium forms a projection in front, called an *auricle*. The muscular coat of the heart forms projections on the inner surface of the ventricles. These are the papillary muscles. The wall of the left ventricle is much thicker than that of the right ventricle.

**Vessels entering and leaving the heart.** The two largest veins, the *superior* and *inferior venae cavae*, which carry venous blood from all parts of the body (except the heart walls) empty into the right atrium. The common venous vessel of the heart itself, the *coronary sinus*, also empties into the heart here.

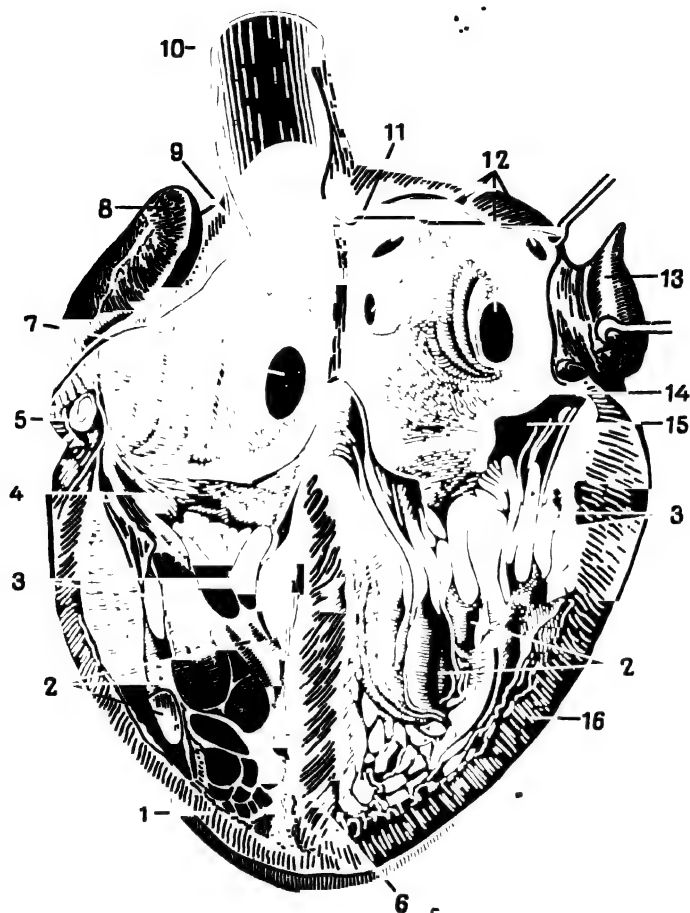
Four *pulmonary veins* which convey arterial blood from the lungs to the heart open into the left atrium.

A pulmonary trunk (*pulmonary artery*), through which venous blood flows to the lungs, arises from the right ventricle.

The largest arterial vessel, the *aorta*, which carries arterial blood for the entire organism, arises from the left ventricle.

**Heart valves.** In the atrioventricular orifices and the orifices from which the aorta and the pulmonary trunk arise there are folds of endocardium which form the heart valves. In the right atrioventricular orifice is the *tricuspid valve*, and in the left orifice is the *bicuspid* or *mitral valve*. Tendinous cords, *chordae tendineae*, extend from the

\* Between the two atria of a foetal heart there is an opening called the *foramen ovale* of the heart; this opening closes up after birth.



**Fig. 106. Heart (opened)**

1—muscular coat of right ventricle; 2—papillary muscles; 3—chordae tendineae; 4—tricuspid valve; 5—right coronary artery (transected); 6—interventricular septum; 7—orifice of inferior vena cava; 8—right auricle; 9—right atrium; 10—superior vena cava; 11—interatrial septum; 12—orifices of pulmonary veins; 13—left auricle; 14—left atrium; 15—bicuspid valve; 16—muscular coat of left ventricle

capillary muscles to the cusps of these valves. There are three semilunar valves in the orifices of the pulmonary trunk and the aorta. The tricuspid and bicuspid valves prevent blood from flowing back from the ventricles into the atria, and the semilunar valves will not allow blood to flow from the aorta and pulmonary trunk back into the corresponding ventricles. In some heart diseases the structure of the valves changes and causes disturbances in the work of the heart (heart defects).

**Vessels of the heart.** The heart muscle works very hard all the time. Therefore it is particularly important that it should receive an uninterrupted supply of oxygen and nutrients. The heart muscle receives its supply from blood flowing through special vessels, not through the heart chambers.

The heart is supplied with blood through the *right* and *left coronary arteries*. They arise from the initial portion of the aorta and are situated in the *coronary sulcus*. The coronary arteries, like the arteries of other organs, divide into smaller branches and then into capillaries. Nutrients and oxygen pass from the blood through the walls of the capillaries into the tissues of the heart wall and waste products pass back into the blood. As a result of this, arterial blood changes into venous blood. Venous blood flows from the capillaries into the veins of the heart. All the veins of the heart drain into a common venous vessel, the *coronary sinus*, which empties into the right atrium. Disturbances in the blood supply of the heart cause changes in its activity. Sometimes the lumens of the intramuscular branches of the coronary arteries become completely occluded with the result that the inflow of blood to the corresponding portion of the heart muscle is obstructed, and myocardial infarction develops.

**Borders of the heart.** It is sometimes necessary for doctors to determine the borders of the heart—their projection on the anterior thoracic wall. The apex of the heart is located in the fifth intercostal space, 8-9 cm from the midsternal line. The upper border of the heart is along the superior border of the cartilages of the third pair of ribs. The right border extends 1-2 cm to the right of the sternum from the third to fifth ribs (inclusive). The left border runs obliquely from the apex of the heart to the cartilage of the third left rib.

In some diseases (for example, heart failure) the heart enlarges and its borders are displaced. The borders of the heart are determined by percussion and evaluation of the resultant sounds, or by X-ray examination.

### *Heart Action*

The work of the heart consists of rhythmic contractions and relaxations of the atria and ventricles. A contraction of the heart is called a *systole*, and a relaxation is called a *diastole*. The contractions and



relaxations of the different parts of the heart take place in a definite order. There are three phases of cardiac activity: phase I—simultaneous contraction of both atria, with the blood passing from the atria into the ventricles, which are relaxing; phase II—simultaneous contraction of both ventricles, the blood is forced into the aorta and the pulmonary trunk, while the atria relax; phase III—the ventricles relax and the atria are also relaxed. This phase of cardiac activity is called the *general pause*. During the general pause blood enters the atria from the venous vessels.

Thus the *systole of the atria is followed by the systole of the ventricles and then by the general pause* (simultaneous relaxation of the ventricles and atria). All three phases constitute a single cycle of the heart action. The relaxation of the ventricles, i.e., the general pause, is followed by another systole of the atria and all phases of the cardiac activity recur.

Atrial systole lasts about 0.1 sec, ventricular systole —0.3 sec, and the general pause—0.4 sec. Thus one complete cycle of heart action takes about 0.8 sec, so that there are 75 contractions of the heart per minute. At rest the number of contractions ranges from 60 to 80 per minute. The rate and intensity of the cardiac contractions vary with environmental conditions. For example, physical exertion increases the work of the heart. A very important part is played by training. In physically-trained people heart action is intensified mainly by stronger cardiac contractions and only to a small extent by acceleration of the heart rate, whereas in untrained people the contrary is the case, i.e., the heart rate becomes much faster.

The heart rate also depends on age. In the newborn the heart contracts about 140 times per minute. The heart rate often increases in old people (to 90-95 per minute).

In diseases involving a rise in body temperature the heart rate usually increases (tachycardia). Only in some diseases is a slower heart rate (bradycardia) observed. Sometimes the regular pattern of cardiac contractions is disturbed (arrhythmia).

An equal amount of blood flows through each half of the heart during an equal period of time. The volume of blood ejected by a ventricle in one contraction is called the *stroke volume* and averages 60 ml. The amount of blood discharged by the ventricle in one minute is referred to as the *cardiac output*. The cardiac output equals the stroke volume multiplied by the number of cardiac contractions per minute.

The state of the heart muscle is investigated by determining the heartbeat and heart sounds, and recording electrocardiograms.

**Heartbeat.** During ventricular systole the heart diminishes in size, and its apex tenses and strikes against the thoracic wall in the fifth intercostal space, left of the sternum (at the site of projection of the

apex. This phenomenon is called a heartbeat. The heartbeat is usually felt by placing the hand on the chest.

**Heart sounds.** The work of the heart gives rise to sounds known as the heart sounds. They may be heard by putting an ear directly to the chest or by means of special instruments (stethoscope and phonendoscope). The procedure of listening to these sounds is called *auscultation*.

Two heart sounds—first and second—are distinguished. The first sound arises at the beginning of ventricular systole and is due to con-

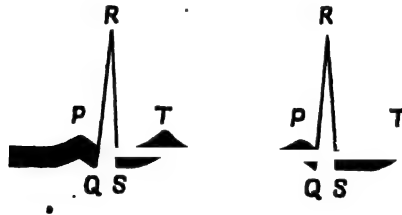


Fig. 107. Electrocardiogram

traction of the ventricular musculature and closure of the AV valves; it is called the *systolic* sound. The second sound is due to the closure of the semilunar valves during ventricular diastole and is called the *diastolic* sound. The first sound is deeper in pitch and longer; the second sound is higher-pitched and short.

In some heart diseases the character of the heart sounds alters. For example, in the case of pathologic changes in the heart muscle the intensity and clearness of the sounds decrease (they become dull). Heart defects, i.e., changes in the normal structure of the heart valves (shrinkage, destruction, etc.), and constriction (stenosis) of the orifices, may cause the heart sounds to lose their clearness and acquire unusual noises, called *murmurs*. The character of the heart sounds indicates the state of cardiac activity; auscultation of the heart is one of the important methods of examination used by doctors.

**Electrocardiography.** The excitation and associated contraction of the heart muscle and other muscles is accompanied by bioelectric phenomena—*action potentials*. These potentials are conducted on the body surface and may be detected and recorded on a special film by means of special instruments. The record of the action potentials of the heart is a complex curve called an *electrocardiogram* (Fig. 107). The electrocardiogram of a healthy person shows five constant waves which are designated by the letters P, Q, R, S and T. The different waves are associated with excitation and contraction of the different

parts of the heart. Changes in the electrocardiogram are observed in cases of heart disease. The character of the changes serves as an indication of the particular disease. For example, the electrocardiogram helps to establish heart diseases caused by a disturbance in the blood supply to the heart muscle. Doctors now make extensive use of electrocardiography. The instrument employed in recording electrocardiograms is called an *electrocardiograph*.

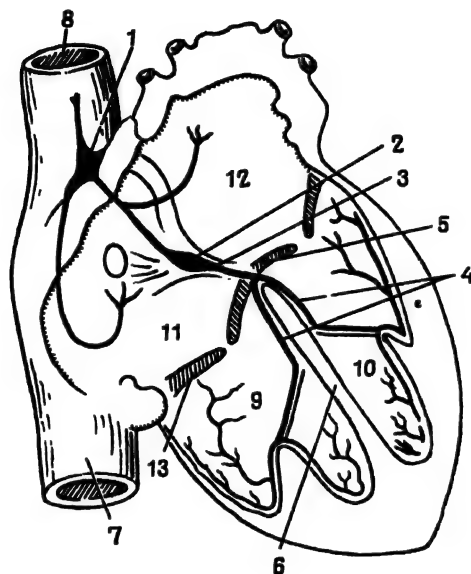


Fig. 108. Conducting system of the heart

1—sino-atrial node; 2—atrioventricular node; 3—bundle of His; 4—branches of bundle of His; 5—bicuspid valve; 6—interventricular septum; 7—inferior vena cava; 8—superior vena cava; 9—right ventricle; 10—right atrium; 11—left ventricle; 12—left atrium; 13—tricuspid valve

**Heart automatism.** This term implies the ability of the heart to contract rhythmically regardless of extraneous stimuli. This ability was discovered in experiments with an isolated heart. The heart of a frog removed from its body continues to contract rhythmically for some time. Isolated hearts of warm-blooded animals are also capable of contracting independently, but for this it is necessary to diffuse a fluid through the system of cardiac blood vessels, to take the place of the blood; a special solution containing various salts in a definite concentration may be used. The Russian scientist A. Kulyabko, using this method, succeeded in reanimating a child's heart several hours after death and in maintaining its contractions for a long time.

Scientists have established that the automatism of the heart is due primarily to the fact that excitation arises in the heart itself and is transmitted to every part of the heart muscle. This function of the heart is performed by a special, so-called conducting system of the heart (Fig. 108), which consists of the nerve cells and special muscle fibres (Purkinje fibres) which differ in structure from the other fibres of the heart muscle. The conducting system includes: (a) the sino-atrial node (node of Keith and Flack) at the junction of the superior vena cava and the atrium, and (b) the atrioventricular node (Tawara node and bundle of His); the atrioventricular node is located in the heart wall at the junction of the right atrium and ventricle. The bundle of His arises at the atrioventricular node and extends to the interventricular septum where it divides into two branches running down to the right and left ventricles. It has been established that excitation arises in the sino-atrial node and is thence transmitted along the other parts of the conducting system to the heart muscle, causing its rhythmic contractions.

Pathological changes in the conducting system disturb the transmission of excitation in the heart muscle, and alter the rhythm and the sequence of work in the different parts of the heart. One of the conditions that may develop is called heart block, in which the ventricles contract at a slower rate than the atria.

### *Systemic (Greater) and Pulmonary (Lesser) Circulation*

All the blood vessels in the human body compose two circuits of blood circulation; the systemic (or greater) circuit and the pulmonary (or lesser) circuit (Plate V).

The **systemic circulation** begins with the aorta which leads from the left ventricle and carries arterial blood to all the organs. The aorta divides into numerous branches, the arteries. The arteries enter the organs where they divide into smaller branches which then form networks of capillaries. From the capillaries the blood, now venous, passes into small veins which form larger veins. From all the veins of the systemic circulation the blood is collected into the superior and inferior venae cavae which empty into the right atrium.

Thus the systemic circulation is a system of vessels through which the blood travels from the left ventricle to the organs and from the organs to the right atrium.

The **pulmonary circulation** begins with the pulmonary trunk which arises from the right ventricle and conveys venous blood to the lungs. The arterial blood flows from the lungs through the pulmonary veins into the left atrium. In other words, the pulmonary circulation is a system of vessels through which the blood moves from the right ventricle to the lungs and from the lungs to the left atrium.

### VESSELS OF THE PULMONARY CIRCULATION

The *pulmonary trunk* (*truncus pulmonalis*) (formerly called the pulmonary artery) is one of the largest human blood vessels in diameter. It leads from the right ventricle and ascends to the level of the fourth thoracic vertebra where it divides into the right and left pulmonary arteries, each of which enters the corresponding lung through its hilus.

In the lung the pulmonary artery divides into smaller branches and then into a network of capillaries which adjoin pulmonary alveoli. Here the interchange of gases takes place—carbon dioxide passes from the blood into the alveoli and oxygen passes from the alveoli into the blood. As a result, the blood changes from venous to arterial blood. The arterial blood flows from the capillaries into the pulmonary veins.

*Two pulmonary veins* lead from each lung, run through its hilus and drain into the left atrium. Arterial blood flows through the pulmonary veins from the lungs to the heart.

### ARTERIES OF THE SYSTEMIC CIRCULATION

#### *Aorta*

The **aorta** is the largest arterial vessel in the body (Fig. 109). It consists of the *ascending part* (*ascending aorta*), the *arch of the aorta* and the *descending part* (*descending aorta*). The descending aorta in its turn is subdivided into the *thoracic aorta* and the *abdominal aorta* (Plate VI).

On leaving the left ventricle the **ascending aorta** runs upward while still in the pericardium. The proximal part of the ascending aorta, the aortic bulb, gives rise immediately above the semilunar valves to the *right* and *left coronary arteries* which supply the heart.

The **arch of the aorta** (*arcus aortae*) is a continuation of the ascending aorta; it is situated in the anterior mediastinum outside the pericardium, arches over the left bronchus and is continuous with the descending aorta. The arch of the aorta gives rise to three large arteries: the *brachiocephalic trunk* (*truncus brachiocephalicus*) or *innominate artery* (a.\* *anonyma*), the *left common carotid artery* and the *left subclavian artery*.

The **innominate artery**, a short thick vessel, in its turn divides into the *right common carotid artery* and the *right subclavian artery* (Fig. 109).

The **common carotid artery** ascends on each side of the neck to the level of the superior border of the thyroid cartilage, where it divides

a. is an abbreviation for artery.

into two branches—the *external carotid artery* and the *internal carotid artery*. To stop bleeding, the common carotid artery is pressed against the tubercle on the transverse process of the sixth cervical vertebra.

The *internal carotid artery* ascends without branching in the neck, enters the cranial cavity through the carotid canal of the temporal bone and divides into branches, the *anterior cerebral* and *middle cerebral arteries* which supply blood to the brain. It also gives off the *ophthalmic artery* which enters the eyesocket through the optic foramen and gives rise to branches supplying the eyeball, lacrimal gland, and the muscles and skin in the region of the forehead.

The *external carotid artery* ascends and passes through the parotid gland behind the mandibular branch. On its way it gives rise to many branches (Fig. 110). These are: (1) the *superior thyroid artery* which supplies the thyroid gland and larynx, (2) the *lingual artery* which supplies the tongue and sublingual gland, (3) the *facial (external maxillary) artery* which goes to the face and ascends to the medial corner of the eye, branching on the way into arteries supplying the submaxillary gland, the muscles and skin of the face, etc., (4) the *occipital artery* which supplies the skin and muscles of the occipital region, and (5) the *pharyngeal artery* which supplies the pharynx. Having given off the aforesaid branches the external carotid artery divides into the internal maxillary artery and the superficial temporal artery. The *internal maxillary artery* supplies blood to the upper and lower jaws, teeth, muscles of mastication, walls of the nasal cavity, hard and soft palates, and the dura mater. The *superficial temporal artery* branches out in the temporal region.

Two branches of the external carotid artery, the *external maxil-*

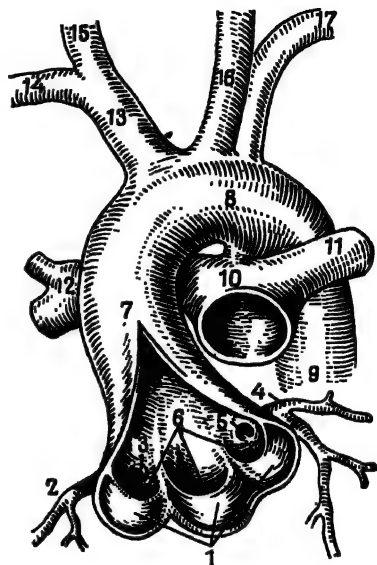


Fig. 109. Beginning of aorta and part of pulmonary trunk

1—aortic semilunar valves; 2—right coronary artery; 3—orifice of right coronary artery; 4—left coronary artery; 5—orifice of left coronary artery; 6—sinuses (pouch-like dilatations) between semilunar valves and wall of aorta; 7—ascending aorta; 8—arch of aorta; 9—descending aorta; 10—pulmonary trunk (pulmonary artery); 11—left pulmonary artery; 12—right pulmonary artery; 13—brachiocephalic trunk (innominate artery); 14—right subclavian artery; 16—left common carotid artery; 17—left subclavian artery



**Fig. 110. Arteries of the head and neck**

1—common carotid artery; 2—external carotid artery; 3—internal carotid artery; 4—maxillary artery; 5 and 6—occipital artery; 7—trapezius muscle; 8—scalenus medius muscle; 9—brachial plexus; 10—thyrocervical trunk; 11—superficial temporal artery; 12—superior thyroid artery; 13—facial artery; 14—lingual artery; 15—branch of maxillary artery to the dura mater

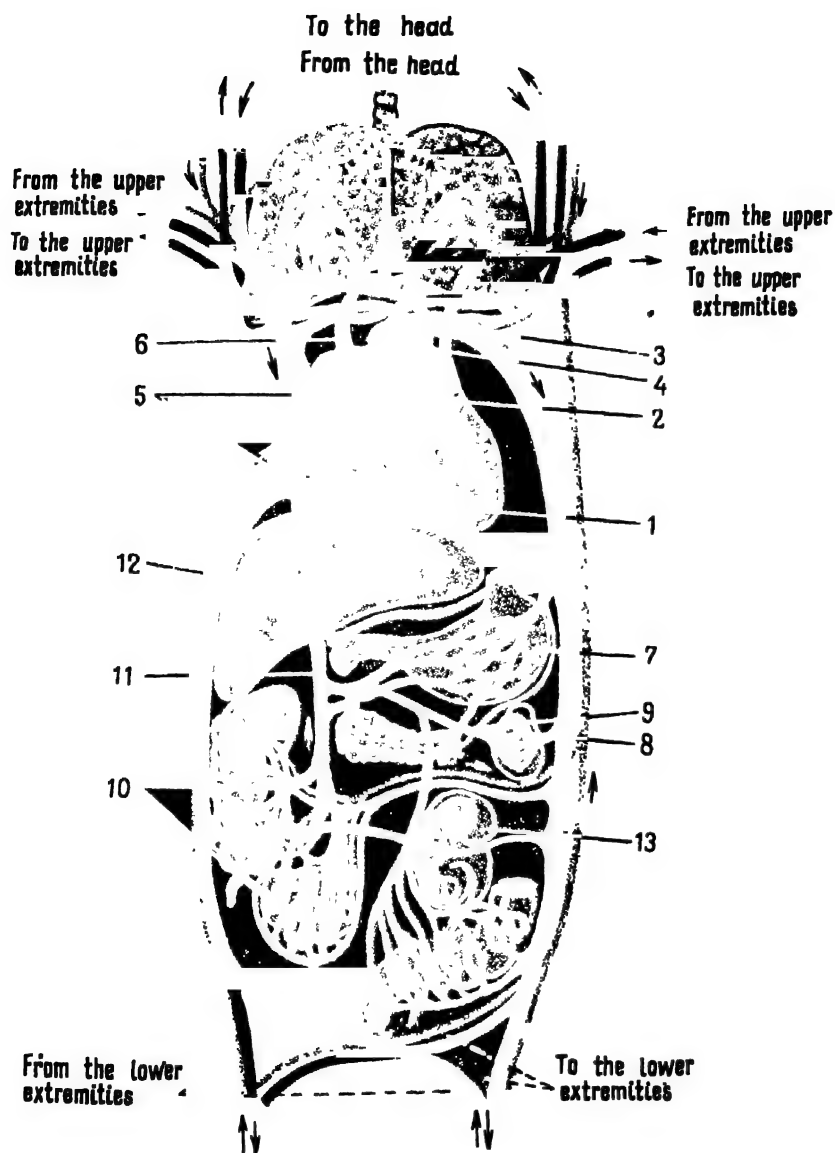


Plate V. Diagram showing blood and lymph circulation. Vessels conveying arterial blood are coloured red; vessels with venous blood—blue; portal vein system—violet; lymph vessels—yellow

1—right half of heart; 2—left half of heart; 3—aorta; 4—pulmonary veins; 5—superior and inferior venae cavae; 6—pulmonary trunk; 7—stomach; 8—spleen; 9—pancreas; 10—small and large intestines; 11—portal vein; 12—liver, 13—kidneys



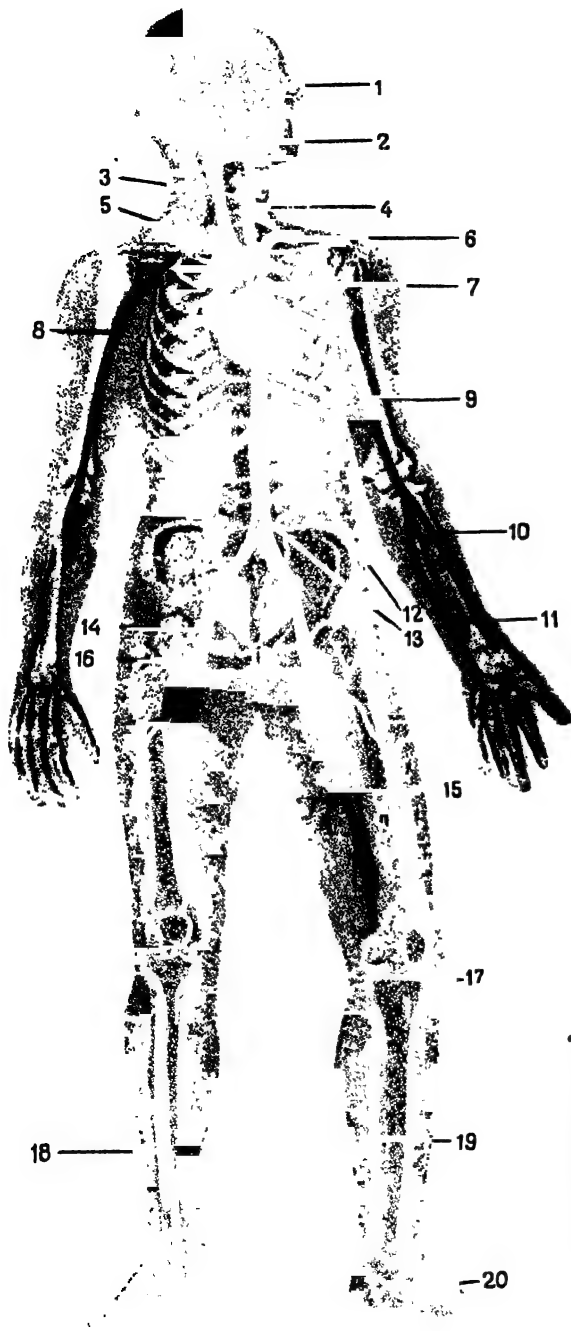


Plate VI. Arterial system (diagram)

1—superficial temporal artery; 2—facial artery; 3—right common carotid artery; 4—left common carotid artery; 5—brachiocephalic trunk (innominate artery); 6—left subclavian artery; 7—arch of aorta; 8—right axillary artery; 9—left brachial artery; 10—radial artery; 11—ulnar artery; 12—renal artery; 13—abdominal aorta; 14—external iliac artery; 15—femoral artery; 16—deep femoral artery; 17—popliteal artery; 18—anterior tibial artery; 19—posterior tibial artery; 20—dorsalis pedis artery

*lary* and the *superficial temporal arteries*, are easily palpated. The external maxillary artery may be pressed against the lower jaw in front of the masseter muscle, and the superficial temporal artery may be pressed against the temporal bone in front of the pinna of the ear.

The *subclavian artery* (a. subclavia) passes on each side above the apex of the lung. Its branches are: (1) the *internal mammary artery*, which supplies the mammary gland, the anterior thoracic wall and the pericardium; (2) the *thyrocervical trunk*, which supplies the thyroid gland, the larynx and the muscles of the neck; (3) the *costocervical trunk*, which supplies the muscles of the neck and the two upper intercostal muscles; (4) the *transverse cervical artery*, which supplies the muscles of the occiput, and (5) the *vertebral artery*, the largest branch of the subclavian artery, which runs through the vertebro-arterial foramina in the transverse processes of the cervical vertebrae and enters the cranial cavity through the foramen magnum, supplying blood to the spinal cord, the cerebellum and the cerebral hemispheres. The two vertebral arteries join and form the basilar artery. The branches of this artery join with those of the internal carotid artery at the base of the brain to form the *circle of Willis*.

The *axillary artery* (a. axillaris) is situated in the axillary fossa (armpit) and is a continuation of the subclavian artery. It gives off branches which participate in supplying blood to the muscles of the shoulder girdle, the capsule of the shoulder joint, and certain muscles of the chest and back (pectoralis major and minor, the serratus anterior and latissimus dorsi). The axillary artery is continuous with the brachial artery.

The *brachial artery* (a. brachialis) (see Plate VI) is situated medially of the biceps brachii muscle; its branches supply the upper arm (muscles, skin and bone) with blood. The largest branch of the brachial artery is the *profunda brachii* which supplies blood to the triceps brachii muscle. In the antecubital fossa the brachial artery divides into the radial and ulnar arteries.

The *radial* (a. radialis) and *ulnar* (a. ulnaris) arteries give off branches which supply blood to the muscles, skin and bones of the forearm. In the lower third of the forearm the radial artery is not covered by muscles and is easily palpated; the pulse is usually taken from the radial artery. From the forearm the radial and ulnar arteries extend to the hand where they form two arterial *volar arches*, *superficial* and *deep*. These arches give off *digital* and *metacarpal arteries*.

### *Thoracic Aorta and Its Branches*

The *thoracic aorta* (aorta thoracica) is located in the posterior mediastinum in front of the thoracic division of the vertebral column. It gives off *visceral branches* to the organs of the thoracic cavity (pe-

ricardium\*, trachea, bronchi, oesophagus) and *parietal branches* to the walls of the thoracic cavity (2-3 branches running to the diaphragm and 10 pairs of intercostal arteries).

The thoracic aorta passes through a special orifice in the lumbar part of the diaphragm into the abdominal cavity where it continues as the abdominal aorta.

### *Abdominal Aorta and Its Branches*

The **abdominal aorta** (aorta abdominalis) is located in front of the lumbar division of the vertebral column, next to and to the left of the inferior vena cava. It gives off *parietal branches* to the walls of the abdominal cavity, and *visceral branches* to its organs (Fig. 111). The parietal branches are the branches to the diaphragm and four pairs of lumbar arteries.

The **visceral branches** of the abdominal aorta are divided into paired and unpaired vessels.

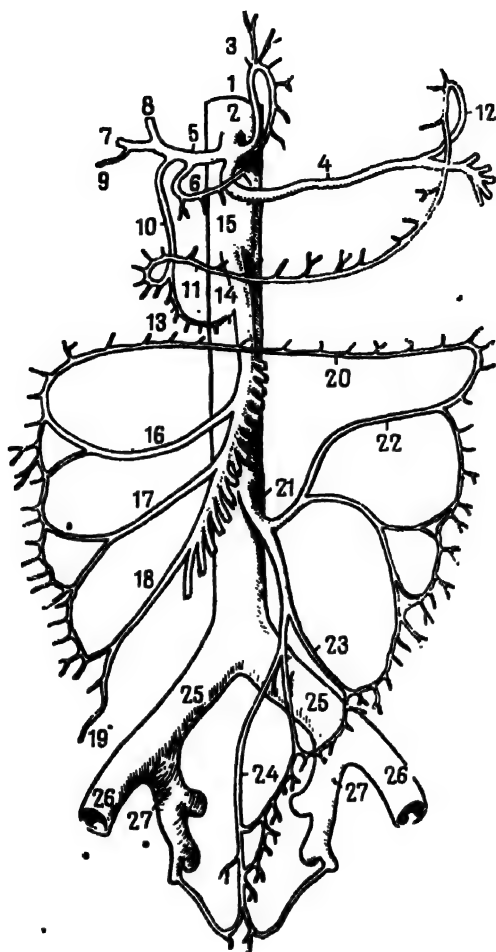
There are three *paired branches*: (1) the **suprarenal arteries** which supply the suprarenal (adrenal) glands; (2) the **renal arteries** which supply the kidneys, and (3) the **internal spermatic arteries** which supply the sex glands (in males they run to the testes through the inguinal canal, and in females they descend into the cavity of the true pelvis, to the ovaries).

There are also three *unpaired branches*: (1) the **coeliac trunk** (truncus coeliacus) or coeliac artery which arises from the aorta immediately below the diaphragm and divides into three branches—(a) *left gastric artery*, (b) *splenic artery*, and (c) *hepatic artery*, which supply blood to the unpaired organs of the upper part of the abdominal cavity, i.e., stomach, spleen, liver, gall bladder, pancreas and part of the duodenum; (2) the **superior mesenteric artery** (a. mesenterica superior) which gives off branches to the caecum and its vermiform appendix, the ascending and transverse colon, the duodenum, and many branches (15-20) to the jejunum and ileum; (3) the **inferior mesenteric artery** (a. mesenterica inferior) which gives off branches to the descending colon, the sigmoid colon and the upper portion of the rectum.

The abdominal aorta then divides again at the level of the fourth lumbar vertebra into the right and left *common iliac arteries*. Each of these arteries in its turn divides at the level of the sacro-iliac joint into the internal and external iliac arteries.

The **internal iliac artery** (a. iliaca interna) runs from the cavity of the true pelvis where it gives off many branches. These branches

\* The heart muscle, as mentioned above, is supplied with blood by the coronary arteries which are branches of the ascending aorta.



**Fig. 111. Branches of abdominal aorta (diagram)**

*1*—abdominal aorta; *2*—coeliac trunk; *3*—left gastric artery; *4*—splenic artery; *5*—hepatic artery; *6, 7, 8, 9, 10, 11, 13* and *14*—branches of hepatic artery (to liver, gall bladder, stomach, pancreas, and duodenum); *12*—branch of splenic artery to stomach; *15*—superior mesenteric artery; *16, 17, 18* and *19*—branches of superior mesenteric artery (to transverse and ascending colon, caecum and vermiform appendix); *20*—anastomosis between branches of superior and inferior mesenteric arteries; *21*—inferior mesenteric artery; *22, 23* and *24*—branches of inferior mesenteric artery (to descending and sigmoid colon and rectum); *25*—common iliac artery; *26*—external iliac artery; *27*—internal iliac artery

The **subclavian vein** receives blood from the largest superficial veins of the neck: the *anterior jugular* and *external jugular veins*.

The **azygos vein** is located in the posterior mediastinum on the right side of the vertebral column; it receives the *hemi-azygos vein* which runs on the left side of the vertebral column. The two veins collect the venous blood from the walls and part of the organs of the thoracic cavity (Plate VII).

Thus the superior vena cava conveys to the heart the venous blood from the upper half of the body—the head, face, neck, upper extremities, walls and organs of the thoracic cavity. The veins of the heart itself are an exception. As mentioned above, these veins form a common venous vessel of the heart, the *coronary sinus*, which drains independently into the right atrium.

### Portal Vein System

The **portal vein** (*vena portae*) is situated in the abdominal cavity, in the right part of the lesser omentum. It collects venous blood from the following unpaired organs: the stomach, small intestine, large intestine (except the lower portion of the rectum), spleen, pancreas and gall bladder (Fig. 114). The portal vein enters the liver through its porta (hence the name of the vein) and divides into smaller branches which form a *capillary network* in the lobules of the liver. The blood then passes into the central hepatic veins and on into 2-3 hepatic veins which drain into the inferior vena cava. It follows that before entering the general circulation the venous blood from the unpaired organs of the abdominal cavity flows through the liver.

As mentioned above, this is how the liver carries out its protective function, and participates in metabolism, etc. The toxic substances flowing into the portal vein from the large intestine are detoxicated, glucose brought by the portal vein from the small intestine is transformed into glycogen, etc.

### Inferior Vena Cava System

The **inferior vena cava** (*vena cava inferior*) is located in the abdominal cavity, to the right of the aorta; it passes through the orifice in the tendinous centre of the diaphragm into the thoracic cavity and

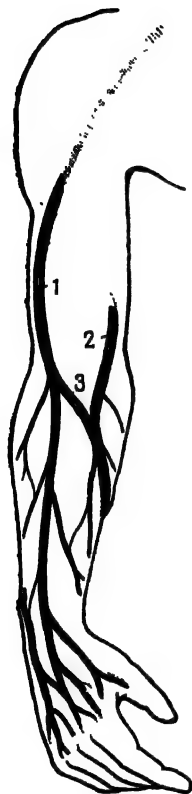
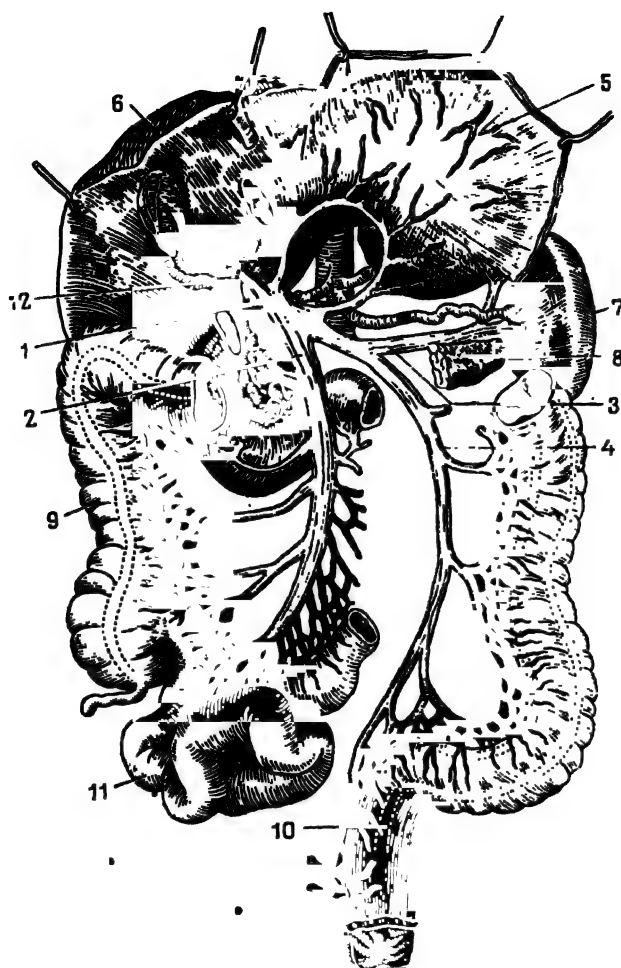


Fig. 113. Superficial veins of the arm  
1—cephalic vein; 2—basilic vein; 3—median cubital vein



**Fig. 114. Portal vein system (anterior view)**

*1—portal vein; 2—superior mesenteric vein; 3—splenic vein; 4—inferior mesenteric vein; 5—stomach (folded upward); 6—liver; 7—spleen; 8—tail of pancreas; 9—ascending colon; 10—rectum (upper portion); 11—loops of small intestine; 12—vein of gall bladder*

drains into the right atrium. It is formed by the junction of the two *common iliac veins* (right and left); each common iliac vein in its turn is formed by the union of the *internal* and *external iliac veins*.

Each *internal iliac vein* collects venous blood from its half of the walls and organs of the true pelvis.

The *external iliac vein* drains the venous blood from the entire leg. The deep veins of the leg run alongside the similarly-named arteries. The superficial veins of the leg include the *saphena magna* and the *saphena parva*. The *saphena magna* begins on the dorsum of the foot, runs up the medial side of the shank and thigh, and empties into the femoral vein in the region of the fossa ovalis. The *saphena parva* is located on the posterior side of the shank and joins the popliteal vein in the region of the popliteal fossa. Injections may be made into the *saphena magna*.

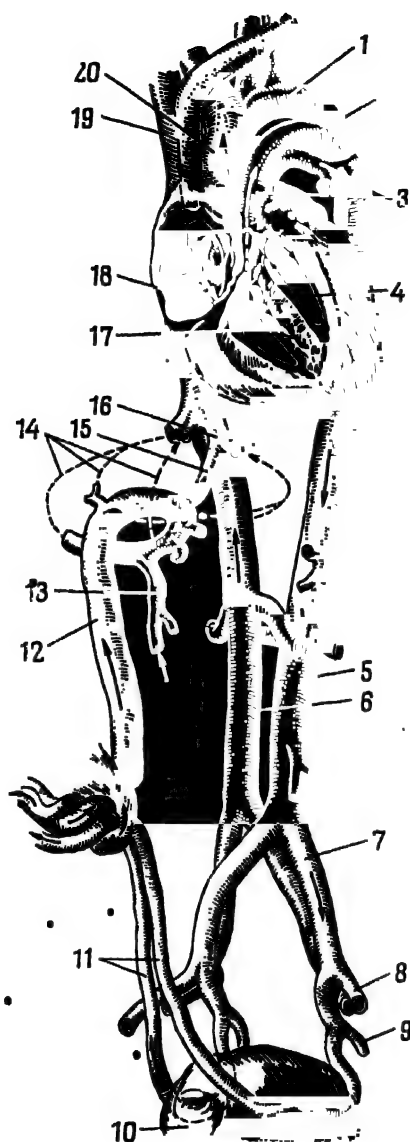
In the abdominal cavity the inferior vena cava is joined by the veins corresponding to the paired branches of the abdominal aorta (*lumbar, internal spermatic, renal* and *suprarenal*), as well as the above-mentioned hepatic veins.

Thus the inferior vena cava conveys to the heart the venous blood from the lower half of the body—the lower extremities, walls and organs of the true pelvis, and the walls and organs of the abdominal cavity.

#### BLOOD CIRCULATION IN THE FOETUS (PLACENTAL CIRCULATION)

The foetus receives nutrients and oxygen from the mother's organism through the placenta. The waste products are eliminated through the placenta. The foetus and placenta are connected through the umbilical cord which carries two *umbilical arteries* and one *umbilical vein*. Blood flows through the umbilical arteries from the foetus to the placenta and through the umbilical vein from the placenta to the foetus.

The cardiovascular system of the foetus exhibits characteristic features. The right and left atria communicate with one another through the *foramen ovale* in their septum. The pulmonary trunk (before branching) communicates with the arch of the aorta through the so-called *ductus arteriosus* (or *Botallo's duct*). Blood circulation in the foetus is as follows (Fig. 115). Arterial blood carrying nutrients and oxygen flows from the placenta through the umbilical vein to the foetus. Near the liver of the foetus the umbilical vein divides into two branches, one extending to the liver and the other, called the *ductus venosus*, opening into the inferior vena cava. Thus the blood in the inferior vena cava is mixed with arterial blood. From the inferior vena cava the mixed blood enters the right atrium, and



**Fig. 115. Diagram of blood circulation in the fetus**

1—arch of the aorta; 2—ductus arteriosus (Botallo's duct); 3—pulmonary trunk; 4—left ventricle; 5—abdominal aorta; 6—inferior vena cava; 7—common iliac artery; 8—external iliac artery; 9—internal iliac artery; 10—bladder; 11—umbilical arteries; 12—umbilical vein; 13—portal vein; 14—branches of portal vein in the liver; 15—ductus venosus; 16—hepatic veins; 17—right ventricle; 18—right atrium; 19—superior vena cava; 20—ascending aorta.  
Arrows indicate direction of blood flow



then passes through the foramen ovale into the left atrium and thence into the left ventricle and the aorta. The superior vena cava of the foetus, like that of the adult, carries venous blood which enters the right atrium, the right ventricle and then the pulmonary trunk. Since the lungs do not function only a small amount of blood passes into them from the pulmonary trunk, while the greater part of it is shunted through the ductus arteriosus into the arch of the aorta. The venous blood from the pulmonary trunk is thus added to the mixed blood flowing through the arch of the aorta, with the result that the descending aorta receives blood containing less oxygen. All the arteries of the systemic circulation of the foetus contain mixed blood; the blood of the ascending aorta, the arch of the aorta and their branches contain relatively more oxygen than that of the thoracic and abdominal aortas and their branches. The umbilical arteries which convey blood from the foetus to the placenta are branches of the internal iliac arteries.

After birth the umbilical cord is tied and cut, and its connection with the placenta is thereby severed. The lungs begin to breathe. Soon after birth the foramen ovale in the interatrial septum closes up, and the ductus arteriosus and venosus become obliterated and transformed into ligaments. Both the systemic and pulmonary circuits begin to function in toto.

Persistence of the foramen ovale of the heart or of the ductus arteriosus after birth (*patent ductus arteriosus*) is a congenital anomaly.

### BLOOD CIRCULATION IN THE BLOOD VESSELS

The movement of blood through the blood vessels is due to the rhythmic work of the heart. During contraction the heart drives the blood under pressure into the arteries. The energy imparted to the blood is spent as the blood moves through the blood vessels. The greater part of this energy is spent on overcoming the friction between the blood particles themselves and the walls of the vessels; the remaining part is spent on imparting speed to the blood flow. The blood pressure is highest at the beginning of the circuit and drops gradually, reaching its lowest level at the end of the circuit. For example, the blood pressure in the aorta is 150 mm Hg, in the medium calibre arteries it is about 120 mm, in the arterioles it is 40 mm, in the capillaries it is 20 mm, in the veins it is still lower, and in the largest veins it is below atmospheric pressure, i.e., negative.

The difference in blood pressure between the different parts of the vascular system is the direct cause of circulation; *the blood moves from the point of higher pressure to the point of lower pressure.*

It should be noted that other factors, besides the work of the heart, contribute to the movement of the blood through the veins. One

of these factors is the aspirating action of the thorax, which is due to the fact that at the moment of inhalation the pressure in the thoracic cavity is somewhat below atmospheric. The negative pressure in the thoracic cavity is conductive to a drop in pressure in the veins draining into the right atrium, which thereby facilitates the flow of blood into the heart.

The movement of blood through the veins is also influenced by adjacent muscles. The venous wall is thin and of low elasticity, and

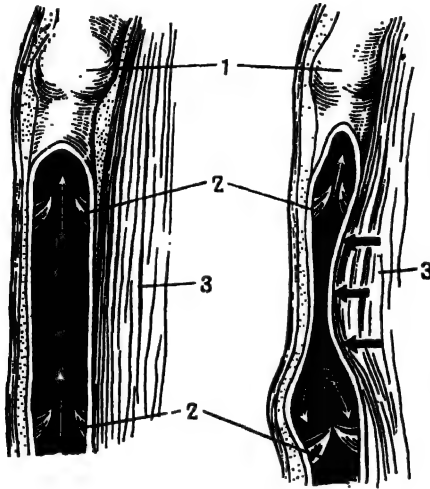


Fig. 116. Diagram showing action of venous valves

1—vein with lower portion opened; 2—venous valves; 3—muscle (left—relaxed; right—contracted). Black arrows show pressure produced on the vein by contracted muscle, white arrows show blood flow in the vein

the contracting muscles can therefore easily compress the veins and drive the blood they contain in the direction of the heart. The venous blood is prevented from flowing back by valves which open only in the direction of the blood flow (Fig. 116). The presence of valves is particularly important in the veins of the lower extremities since in these veins the blood flows upward.

The blood is ejected from the heart into the aorta and the pulmonary trunk in spurts during ventricular systole, but flows through the blood vessels in a continuous stream.

The continuity of the blood flow is due to the fact that the arterial walls are elastic; they easily stretch and return to their normal state. When blood is ejected from the heart the blood pressure on the arterial walls rises and they stretch. During ventricular diastole no blood enters the vessels from the heart and the pressure on their walls

drops. The vessels return to their original shape because of the elasticity of their walls, and at the same time exert pressure on the blood, driving it along. Hence, the movement of the blood is uninterrupted.

*Linear* and *volumetric* rates of blood flow are distinguished. The linear rate implies the speed with which the blood moves along the blood channel. The *linear rate* of blood flow differs in the different parts of the circulatory system and depends mainly on the total size of the lumens of the vessels. The smaller the lumen of a vessel, the faster the rate of flow of the blood, and vice versa. The blood flow is fastest in the aorta—about 0.5 m/sec. In the arteries whose total lumen is larger than that of the aorta the blood flows at a slower rate, averaging 0.25 m/sec. Since the total lumen of the capillaries is many times as large as that of the other vessels the blood moves through them at the slowest rate—only about 0.5 mm/sec (1,000 times slower than in the aorta). In the veins the blood flow is somewhat slower than in the arteries—about 0.2 m/sec.

The *volumetric rate* of blood flow indicates the amount of blood flowing through unit cross-section of a vessel per unit of time. It is the same in the aorta, pulmonary trunk, arteries, capillaries and veins.

### BLOOD PRESSURE

The blood circulating through the blood vessels exerts a certain pressure on their walls. Observations have shown that normally the blood pressure is constant and, if it varies, the variation is negligible. Blood pressure depends on two basic factors: (1) the force with which the blood is ejected from the heart by the contraction of its muscles, and (2) the resistance of the walls of the blood vessels, which the blood has to overcome as it circulates.

The gradual decrease in blood pressure as the blood moves from the beginning of the circuit to the end is due to the fact that the energy imparted to the blood by the contraction of the heart is spent on overcoming the friction between the blood and the walls of the vessels. The greatest resistance to blood flow is in small arteries and capillaries.

But in each vessel the blood pressure is subject to continuous variations associated with the different phases of the heart action. It is higher during ventricular systole than during diastole, and so **maximal** or **systolic** and **minimal** or **diastolic** blood pressures are distinguished. It is also customary to determine the *pulse pressure* which is the difference between the maximal and minimal pressures.

Doctors usually measure the blood pressure in the brachial artery. In an adult the maximal pressure in this artery is 110-125 mm Hg, and the minimal is 65-80 mm Hg. In children the blood pressure is lower: in the newborn—70/34 mm Hg, in children 9-12 years of age—

—105/70 mm Hg, etc. In older people the blood pressure slightly increases.

During physical work the blood pressure rises, and during sleep it drops.

In diseases associated with disturbances in blood circulation the blood pressure is altered. In some cases it is elevated—**hypertension**, and in others it is lowered—**hypotension**. Hypotension may be cau-

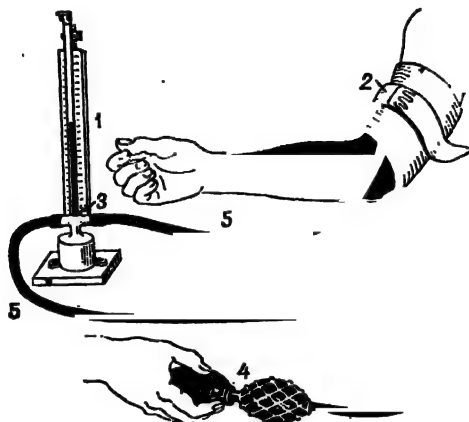


Fig. 117. Sphygmomanometer, an instrument for measuring blood pressure in man  
1—mercury manometer; 2—cuff; 3—valve; 4—rubber bulb; 5—rubber tubes connecting manometer to cuff and bulb

sed by a decrease in the number and intensity of the cardiac contractions, dilation of arteries, especially of the smaller ones, and considerable blood losses.

A big drop in blood pressure leads to serious disturbances in the organism and sometimes may be dangerous to life. Continued high pressure is observed in hypertensive vascular disease.

**Measuring of blood pressure.** Blood pressure is measured by special instruments—a *sphygmomanometer* and a *tonometer*. The Riva-Rocci sphygmomanometer (Fig. 117) consists of a mercury manometer, a hollow cuff and a rubber bulb; the manometer is connected with the cuff and the bulb by rubber tubes. The tonometer contains a metal manometer instead of a mercury one. The most accurate method of determining blood pressure in man is that of the Russian physician Korotkov.

The Korotkov method is as follows: the cuff is attached to the patient's upper arm, the phonendoscope is placed in the antecubital fossa for auscultating the pulse in the brachial artery and air is pum-

ped into the cuff with the aid of the rubber bulb to compress the artery until blood ceases to flow through it; then by means of a special screw the air is very slowly released from the cuff until a characteristic sound appears in the phonendoscope. At this moment the height of the mercury column in the manometer is noted; this point indicates the *maximal pressure*. The air continues to be released from the cuff until the sound in the phonendoscope disappears. At this moment the height of the mercury column in the manometer is again noted; this height indicates the *minimal pressure* in the given artery.

### PULSE

The intermittent changes in the shape of arterial walls are called the pulse. They are the result of the rhythmic contractions of the heart. During ventricular systole blood is driven into the aorta and its walls are distended. During ventricular diastole the elastic walls of the aorta return to their normal shape. The intermittent changes in the walls of the aorta are transmitted to the walls of its branches, the arteries.

The pulse may be palpated in the superficial arteries by pressing them against the underlying bones. The pulse is usually taken on the radial artery in the lower portion of the forearm. Determination of the pulse includes examination of its rhythm, rate, tension and other properties. The properties of the pulse depend on the work of the heart and the state of the vessel wall. It follows that the state of cardiac activity may be judged from the character of the pulse. Usually every patient's pulse is taken.

The pulse rate of an adult at rest is 60-80 beats per minute. In children the pulse rate is faster; in the newborn it reaches 140 per minute, in 5-year-old children it is 100 per minute, etc. The pulse rate corresponds to the number of cardiac contractions.

### REGULATION OF CARDIOVASCULAR ACTIVITY

The activity of the heart and blood vessels varies with the functional state of the other systems of organs and the external environment of the organism. For example, eating, physical work, emotional experiences, changes in the external environment (temperature of the air, atmospheric pressure, etc.), and many other factors cause functional changes in the cardiovascular system. The activity of the heart and blood vessels is regulated by the nervous system and humorally.

The heart is abundantly supplied with parasympathetic (from the vagus nerve) and sympathetic nerve fibres. I. Pavlov established that the nerves running to the heart exert slowing, weakening, ac-

celerating and intensifying actions and affect the conduction in the heart and its excitation. The parasympathetic fibres exert a slowing and weakening action on the heart; they cause a slowing of the rhythm and a decrease in the strength of cardiac contractions, in the excitability of the heart and in the rate of conduction of excitation in the heart. The sympathetic fibres exert an accelerating and intensifying action on the heart; they cause an acceleration of the rhythm and an increase in the strength of cardiac contractions (Fig. 118), in cardiac excitability and in the rate of conduction of excitation in the heart. The presence of nerve fibres which intensify the work of the

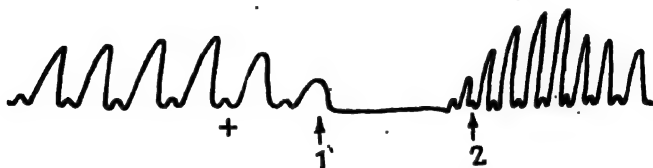


Fig. 118. Influence of the vagus and sympathetic nerves on the work of the heart  
1—action of the vagus; 2—action of the sympathetic nerve

heart was established by Pavlov in his experiments on animals. He named these fibres the *intensifying nerve*. Under the influence of the intensifying nerve the metabolism in the heart muscle increases. Such an influence of the nervous system on the tissues is called a *trophic influence*.

The walls of the blood vessels are also equipped with nerves. Motor nerve fibres have been found to terminate in the muscular coat of the blood vessels. Some of them (sympathetic) cause constriction of the blood vessels and are called *vasoconstrictors*. Others cause dilation of the blood vessels and are called *vasodilators*.

The walls of the blood vessels, like those of the heart, also have sensory nerve fibres with their endings, receptors, which react to changes in the blood pressure and in the chemical composition of the blood.

The centres regulating the activity of the cardiovascular system are located in the medulla oblongata and the spinal cord. Changes in the work of the heart and blood vessels occur reflexly through the nervous system in response to various stimuli acting on the organism (heat, cold, pain, changes in the muscles during work, etc.). The impulses arising from stimulation of the receptors are transmitted along sensory nerves to the central nervous system where they cause excitation of the centres of cardiovascular activity. Impulses from the centres are sent along the motor nerves to the heart and blood vessels. As a result, the work of the heart changes as necessary, and the blood

vessels become either dilated or constricted. For example, during physical work cardiac activity is intensified and the vessels through which blood flows to the working muscles dilate. During digestion the blood supply to the digestive glands increases.

It should be remembered that in a healthy man the blood pressure may change under different conditions, but these changes are temporary. The rise or fall in blood pressure stimulates the receptors imbedded in the walls of the blood vessels. The cardiovascular system responds reflexly by a change in its activity, which leads to establishment of normal blood pressure. It has been found, in particular, that a sensory nerve runs to the arch of the aorta; this nerve has been named the *depressor nerve* (Fig. 119) because its excitation causes a reflex drop in blood pressure. Elevation of the blood pressure in the arch of the aorta stimulates the endings of this nerve. The excitation is transmitted to the medulla oblongata, to the centres of cardiovascular activity.

In response the nerve centres send impulses to the heart and the blood vessels.

Under the influence of these impulses the heart action weakens and the blood vessels dilate with the result that the blood pressure drops.

As mentioned above, Pavlov named this principle of regulation of the function of the organs self-regulation.

Humoral regulation of the activity of the heart and blood vessels

can be seen in the influences exerted by the hormones, salts and other substances circulating in the blood. For example, *adrenalin* (hormone) causes acceleration and intensification of cardiac contractions, as well as constriction of the vessel lumens (the vessels of the heart are dilated by adrenalin). It therefore acts like the sympathetic nerves. *Histamine*, *acetylcholine* and other substances exert vasocons-

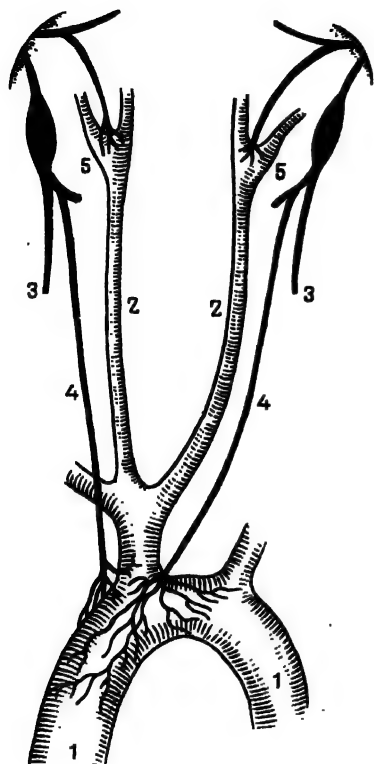
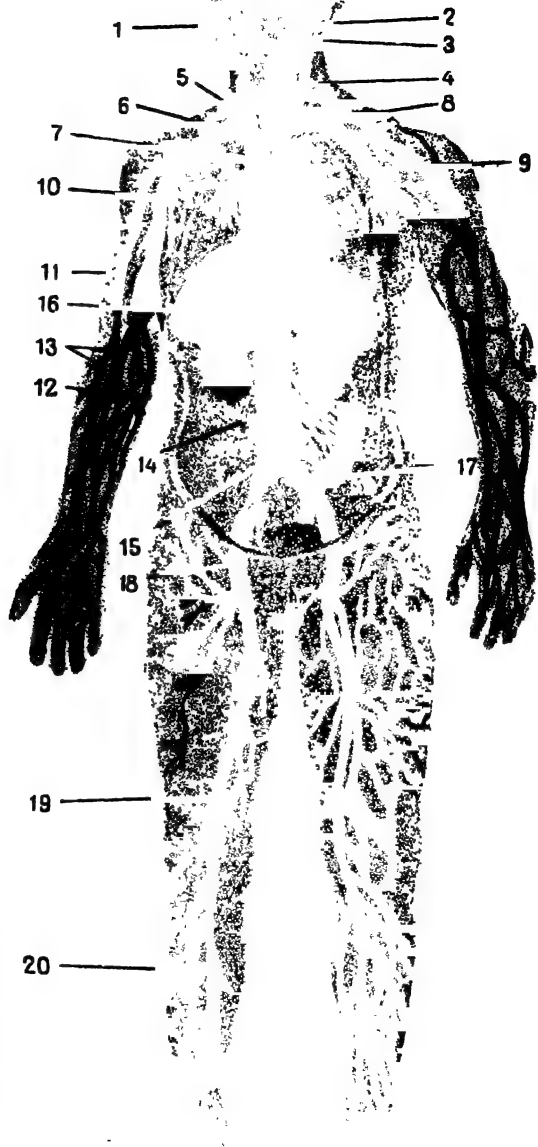


Fig. 119. Diagram of the depressor nerve

1—arch of aorta; 2—carotid arteries;  
3—vagus nerves; 4—depressor nerves;  
5—internal carotid artery



**Plate VII. Venous system (diagram)**

1—facial vein; 2—pterygoid plexus; 3—common facial vein; 4—internal jugular vein; 5—left brachiocephalic (innominate) vein; 6—right brachiocephalic (innominate) vein; 7—superior vena cava; 8—subclavian vein; 9—axillary vein; 10—brachial vein; 11—cephalic vein; 12—basilic vein; 13—median cubital vein; 14—inferior vena cava; 15—abdominal aorta; 16—portal vein; 17—left common iliac vein; 18—femoral vein; 19 and 20—saphena magna





trictor action. The influence of humoral factors on the work of the heart is closely connected with nervous regulation.

It has been established, for example, that if the cardiac fibres of the vagus and sympathetic nerves are excited, chemical substances are liberated in their endings, which act like the vagus or sympathetic nerves.

The heart functions normally if the blood contains salts of potassium and calcium in definite concentrations.

*Potassium* acts on the heart in a manner similar to the vagus nerve; *calcium* acts like the sympathetic nerve. A change in the proportions of the potassium and calcium salts in the blood leads to disturbances in cardiac activity.

Doctors use various medicinal substances to influence the work of the heart and blood vessels.

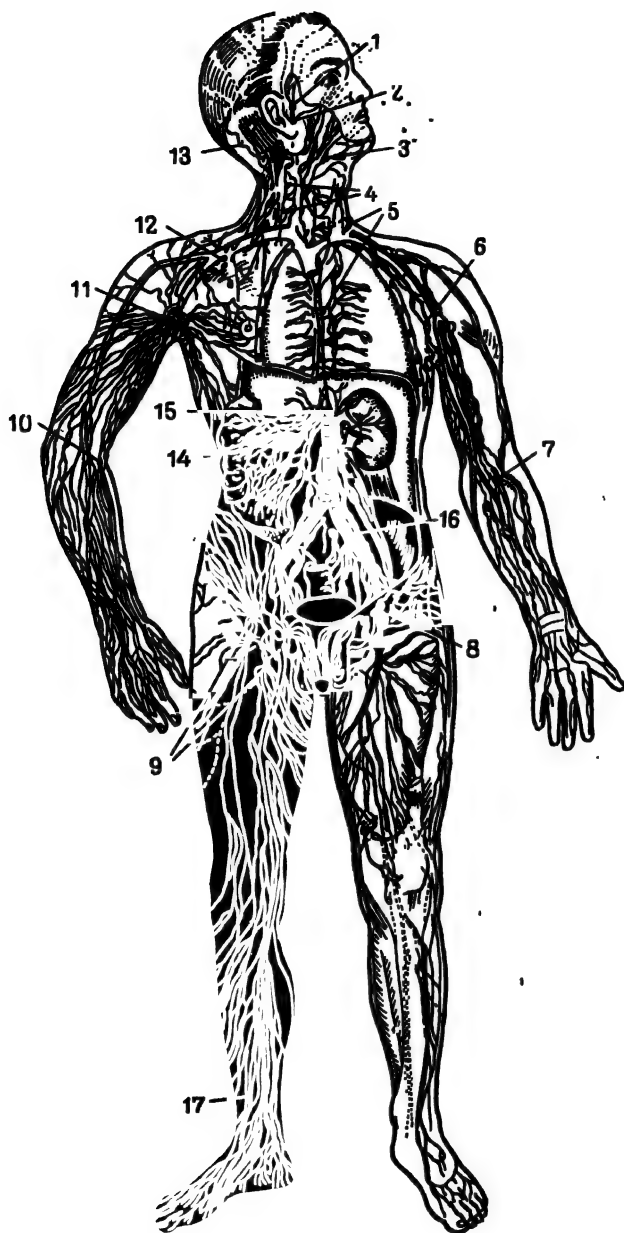
Besides general changes, local changes may also take place in the lumens of the blood vessels of the organism. Local changes are observed when hot water bottles, mustard plasters, etc., are used. Both local and general dilatations or constrictions of vessels are of a reflex nature.

In conclusion it should be noted that the cardiovascular system is influenced by the cerebral cortex. This influence manifests itself, for example, in changes in cardiac activity under emotional stress, while waiting for work to begin, and in response to the action of various verbal stimuli.

### LYMPHATIC SYSTEM

In addition to the vascular system, the human organism also has a lymphatic system. It consists of lymph vessels, lymph nodes (Fig. 120) and the lymph circulating through them.

The composition of lymph is similar to that of the blood plasma; it contains lymphocytes in suspension (usually it has no other cells). Lymph is continuously being formed in the organism and conveyed through lymph vessels to the veins. The process of lymph formation is connected with the metabolic interchange between the blood and the tissues. As blood flows through the blood capillaries, part of the plasma containing nutrients and oxygen passes from the vessels into the surrounding tissues and forms the tissue fluid. The tissue fluid bathes the cells, and a continuous metabolic interchange takes place between the fluid and the cells; nutrients and oxygen enter the cells and the waste products pass into the fluid. Part of the tissue fluid containing waste products returns to the blood through the walls of the blood capillaries. At the same time some tissue fluid passes not into the blood capillaries, but into the lymph capillaries and forms the lymph. The process of formation and outflow of lymph intensifies during increased activity of the organs.



**Fig. 120. Lymphatic system (diagram)**

*1 and 2—anterior auricular lymph nodes; 3—submaxillary nodes; 4—cervical nodes; 5—thoracic duct; 6 and 11—axillary nodes; 7 and 10—cubital nodes; 8 and 9—inguinal nodes; 12—subclavian nodes; 13—occipital nodes; 14—mesenteric nodes; 15—beginning of thoracic duct (cisterna chyli); 16—iliac nodes; 17—superficial lymph vessels of shank*

The lymphatic system is thus an additional outflow system which supplements the venous system. It plays a very important part in metabolism and in the circulation of fluids in the organism; disturbances in the outflow of lymph lead to metabolic disorders in the tissues and to the development of oedema.

It should also be noted that the lymphatic system plays an important role in the process of absorption of nutrients (p. 154-5).

The lymph flowing out of the small intestine contains droplets of fat which colour it milky-white (the lymph flowing out of other organs is usually colourless). The lymph vessels leading from the small intestine are therefore called *lacteals* (Latin *lac* milk).

Almost all organs have a large number of lymph vessels. The system of lymph vessels begins with lymph capillaries which are continuous with vessels of a larger diameter. The walls of lymph vessels are very thin and in their microscopic structure resemble the walls of veins. Like many veins, lymph vessels possess valves. In the organs the lymph vessels usually form two networks; one superficial and one deep. Unlike the blood, the lymph flows only in one direction—out of the organs (never into the organs)—and drains into larger lymph vessels which are common to several organs. The movement of the lymph is due to contraction of the walls of the lymph vessels and contraction of the muscles between which these vessels run.

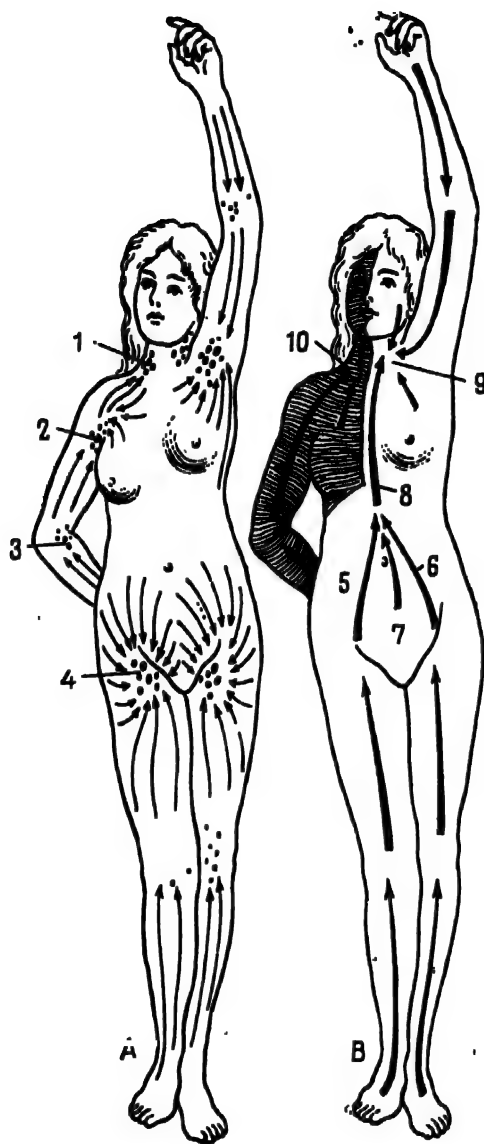
The lymph from all the lymph vessels of the human body collects into the two largest lymph vessels or ducts: the thoracic duct and the right lymphatic duct.

The thoracic duct (ductus thoracicus) begins in the abdominal cavity with a dilatation called the *cisterna chyli*, and then passes through the aortic orifice of the diaphragm into the thoracic cavity (into the posterior mediastinum). From the thoracic cavity it extends to the neck region on the left side and drains into the left venous angle formed by the junction of the left subclavian and internal jugular veins. The thoracic duct receives lymph from both lower extremities, the organs and walls of the true pelvis, the organs and walls of the abdominal cavity, the left upper extremity, the left half of the thorax, and the head, face and neck (Fig. 121).

The right lymphatic duct is a short vessel located in the region of the neck, on the right side. It drains into the right venous angle formed by the junction of the right subclavian and internal jugular veins. This duct collects lymph from the right half of the thorax, the right upper extremity, and the right half of the head, face and neck (see Fig. 121).

It should be remembered that, together with the lymph, the lymph vessels may also carry pathogenic microbes and particles of malignant tumours.

The course of the lymph vessels is intercalated by lymph nodes.



**Fig. 121. A—diagram showing location of lymph nodes; B—diagram showing location of regions from which lymph collects in the thoracic duct and the right lymphatic duct (the region of the latter is shaded)**

**1—cervical lymph nodes; 2—axillary nodes; 3—cubital nodes; 4—inguinal nodes; 5—right lumbar trunk; 6—left lumbar trunk; 7—intestinal trunk; 8—thoracic duct; 9—site where thoracic duct drains; 10—site where right lymphatic duct drains**

Through some lymph vessels the lymph flows to the nodes (*afferent vessels*), and through other vessels it flows out of them (*efferent vessels*).

The **lymph nodes** (*nodi lymphatici*) are small roundish or elongated masses of lymphatic tissue. Each node has a connective-tissue capsule which gives off trabeculae into the interior (Fig. 122). The framework of the lymph nodes consists of reticular tissue. Between the trabeculae are nodules which form lymphocytes. Consequently, lymph nodes are haematopoietic organs. They also have a protective function; they may retain pathogenic microbes (if these enter the lymph nodes). In such cases the lymph nodes enlarge, become more compact and may be palpated.

As a rule, lymph nodes are arranged in groups. From each organ or part of the body the lymph flows into definite lymph nodes. These nodes are called *regional nodes* (Latin *regio* region). The nodes for the lymph vessels of the arm are the cubital and axillary nodes, and those for the vessels of the legs are the popliteal and inguinal nodes. On the neck there are the submaxillary, deep cervical (along the course of the internal jugular vein) and other nodes. In the thoracic cavity many lymph nodes are situated at the bifurcation of the trachea and near the hili of the lungs. There are many lymph nodes in the abdominal cavity (particularly in the mesentery) and in the pelvic cavity.

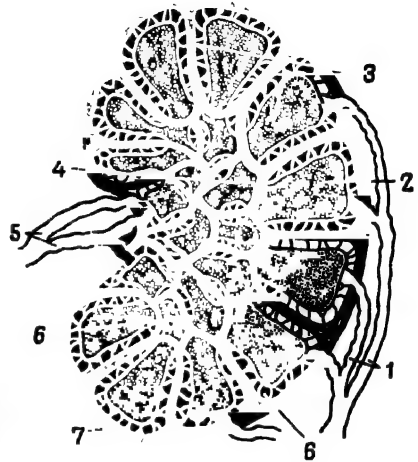


Fig. 122. Diagram showing structure of lymph node

1—afferent lymph vessels; 2 and 4—nodules in the substance of the node; 3—trabeculae; 5—efferent vessels; 6—lymph sinuses; 7—capsule of node

## *Nervous System*

During the long process of evolution animals developed a nervous system.

In virtue of the continuous changes in the conditions of existence of animal organisms the structure and functions of the nervous system have become increasingly more complicated. In a complex organism the nervous system plays the leading role in regulating all physiologic processes and in effecting the connections of the organism with the external environment.

The nervous system is especially highly developed in man, who has a brain which is the organ of thinking. This development is associated primarily with man's labour.

In F. Engels' definition: "First labour, after it, and then with it, articulate speech—these were the two most essential stimuli under the influence of which the brain of the ape gradually changed into that of man, which for all its similarity to the former is far larger and more perfect."\*

### ROLE OF THE NERVOUS SYSTEM

*The nervous system regulates the activities of the different organs and of the entire organism.* Muscular contraction, glandular secretion, heart action, metabolism and the many other processes continuously operating in the organism are controlled by the nervous system.

*The nervous system links the various organs and systems, co-ordinates all their activities and ensures the integrity of the organism.*

The working of each organ or system of organs may be affected by various conditions. A change in the function of one organ or system

\* F. Engels, *Dialectics of Nature*, Foreign Languages Publishing House, Moscow, 1954, p. 238.

of organs leads to changes in the functions of other organs and systems. For example, during physical work involving intensive muscular contraction the metabolism in the muscles increases, which consequently increases the requirement in nutrients and oxygen. A reflex response causes the heart and lungs to work more intensively, with the result that the flow of blood to the muscles increases. At the same time heat production and heat losses increase, the excretory organs work harder, etc.

*The unity of the organism and its external environment is effected through the nervous system.* All the outside stimuli are perceived by the nervous system through the sense organs. In response to the stimuli the functions of the various organs change and the organism adapts itself to its surroundings or, as I. Pavlov put it, the organism is equilibrated with the external environment. This equilibrium forms the basis of the organism's vital activities. Thus in response to the ingestion of food the activity of the digestive glands increases and is adapted to the character of the ingested food. A rise in temperature of the surrounding air causes an increased flow of blood to the skin and greater perspiration, which prevents overheating of the organism.

It should be remembered that, unlike animals, man can himself considerably change his external environment.

*Man's brain is the material basis of thinking and speech.* I. Pavlov demonstrated that man's so-called psychic activity is based on physiological processes operating in the cerebral cortex.

## GENERAL INFORMATION ON THE STRUCTURE OF THE NERVOUS SYSTEM

The nervous system includes the brain, spinal cord, and nerves. The brain and spinal cord constitute the central part of the nervous system or, as it is customarily referred to the **central nervous system**. The brain gives rise to 12 pairs of cranial nerves, and the spinal cord to 31 pairs of spinal nerves. These nerves give off branches to the different organs and tissues. The nerves and their branches constitute the **peripheral nervous system**. Although the nervous system is divided into central and peripheral parts, these parts form a single system.

The brain and spinal cord are large accumulations of nerve cells, their processes and neuroglia (see "Nervous Tissue"). The brain and spinal cord are composed of grey and white matter. The **grey matter** consists of nerve cells, and the **white matter** consists of nerve fibres which are processes of the nerve cells. The location of the white and grey matter differs in the different parts of the central nervous system. In the spinal cord the grey matter forms the inner part, and the white matter the outer part. In the brain the grey matter forms the outer part in some places and the inner part in others. The continuous layer



of grey matter on the surface of the cerebral hemispheres is called the **cerebral cortex**. Various parts of the brain have accumulations of nerve cells (grey matter) located inside white matter. These accumulations are called *nuclei*. Accumulations of nerve cells are also found outside the brain and spinal cord (for example, in the intervertebral foramina, the jugular foramen, etc.). Such accumulations are called **ganglia**.

The brain and spinal cord contain a very large number of blood vessels. Nervous tissue needs an uninterrupted supply of nutrients and oxygen.

Injury to the substance of the brain or spinal cord (trauma, tumour, etc.) or a disturbance in the blood supply is accompanied by impairment of various functions of the organism. The character of the impairment depends on the part of the brain that is injured.

Some cases involve muscular paralysis, others—loss of sensitivity, still others—speech disturbances; some injuries may simultaneously affect several functions.

The various parts of the central nervous system communicate with each other through nerve fibres which constitute the white matter of the brain and spinal cord.

The **nerves** are bundles of nerve fibres with an outer connective-tissue covering. Some nerves consist mainly of motor nerve fibres and are called *motor* or *efferent nerves*. The fibres of motor nerves are the processes of the nerve cells which form the nuclei of these nerves. Such nuclei are located in the brain and spinal cord. Other nerves consist mainly of sensory nerve fibres and are called *sensory* or *afferent nerves*. The fibres of the sensory nerves are processes of the nerve cells which compose the ganglia of these nerves. There are also nerves which include both motor and sensory nerve fibres. These are called *mixed nerves*.

The motor nerve fibres terminate in organs (for example, in muscles) with motor endings. The sensory nerve fibres terminate in organs (for example, in the skin) with sensory endings or *receptors*.

All organs are supplied with nerves or, as it is usually said, they are innervated. The central nervous system communicates with all organs and tissues through the nerves.

### MAIN PROPERTIES OF NERVOUS TISSUE

Every living tissue possesses the ability to enter into an active state—a state of *excitation*—in response to stimulation. This property is called **excitability**. Excitability is an inherent property of nervous tissue.

In the living organism excitation of nervous tissue occurs as the result of stimulation of sensory nerve endings (receptors). The org-

anism is continuously exposed to various stimuli—acoustic, optic, thermal, gustatory, etc. Excitation arises in the receptors in response to these stimuli. Nervous tissue is characterized by the fact that excitation does not remain at the site of its origin but is transmitted along nerve fibres. The property of nervous tissue to transmit excitation is called **conductivity**.

The conduction of excitation along nerve fibres is accompanied by appearance of bio-electric phenomena, called *action potentials*, in nervous tissue; these action potentials can be registered by means of special, very sensitive instruments.

Using various methods of observation scientists have elucidated many laws governing the conduction of nervous excitation. In the frog excitation is conducted along the nerves at the rate of 23-27 m/sec. In man the rate of conduction of nervous excitation varies between 0.5 and 100 m/sec and depends on the thickness of the nerve fibres.

Excitation is conducted in the nerves in *isolation* (separately) along each nerve fibre. Excitation is never transmitted from one nerve fibre to an adjacent nerve fibre. It follows that excitation may either be transmitted along all the fibres forming a nerve, or just along some of them. This makes possible the contraction of individual muscle fibres and certain muscles, and not necessarily the entire group of muscles innervated by a particular nerve.

The nerve must be intact if it is to conduct excitation. If its continuity is disrupted (wound, injury, etc.) excitation is not conducted through the damaged portion, and the organ innervated by the nerve does not function properly. In cases of injury to motor nerves the result is paralysis of the muscles innervated by these nerves; injury to the sensory nerves innervating the skin results in impairment of cutaneous sensitivity.

The conductivity of a nerve may be impaired temporarily by certain substances; this factor is used by doctors. If a novocain solution (or other analgesic) is administered at the site of a sensory nerve or its endings the conductivity of the nerve will be temporarily disturbed, with the result that a certain part of the body will become anesthetized.

Special experiments on the stimulation of nerves have established that excitation may be transmitted along nerve fibres in both directions from the point of application of the stimulus. Normally, however, nervous excitation is conducted only in one direction. Nerve cells are connected with each other and form *chains of neurons*, the *axon* of one cell extending to the *dendrite* or *body* of another cell. The point at which an impulse passes from an axon of one neuron to the dendrite or cell body of another is called a *synapse*. Nervous excitation is transmitted along the chain of neurons only in the den-

drite-body-axon direction. This is due to the fact that conduction in the synapses is possible only in one direction—from the axon of one nerve cell to the dendrite or body of another cell, or from the axon of the nerve cell to the working organ. Practically, this means that *excitation (nerve impulses) is transmitted along sensory nerves from the periphery (from the receptors) to the central nervous system, and along motor nerves from the nerve centres to the periphery, i.e., to the organs (muscles, glands, etc.).*

In the synapses the rate of conduction of excitation is slower than in the nerve fibres, and nervous excitation may even be delayed in them.

### REFLEXES AND THE REFLEX ARC

The activity of the nervous system is of a reflex character. *A reaction of the organism effected by the central nervous system in response to a stimulus is called a reflex.* The various stimuli to which the organism is continuously exposed are perceived by receptors. The organism responds to these stimuli in a certain way. For example, in response to a light blow on the tendon of the quadriceps femoris (below the patella) this muscle contracts and the leg is jerked upward. If a bright light falls onto the eyes the pupils contract. Stimulation of the gustatory papillae of the tongue with food results in the secretion of saliva. All these responses of the organism are effected through the nervous system. The excitation arising in the receptors is transmitted along sensory nerves to the central nervous system, and from here along motor nerves to the different organs. The organs respond with a definite activity (muscular contraction, glandular secretion, etc.).

*The path along which the nervous excitation is transmitted during the reflex is called the reflex arc.* The reflex arc consists of the following parts: receptors, sensory nerve fibres (sensory nerves), the centre of the given reflex which is an accumulation of nerve cells in the brain or spinal cord, motor nerve fibres (motor nerve), and the working organ (Fig. 123). The initial moment of any reflex is the appearance of excitation in the stimulated receptors. Normally, each receptor perceives a certain stimulus; the retina of the eye receives optic stimuli, the ear receives acoustic stimuli, the papillae of the tongue receive gustatory stimuli, etc.

The integrity of all the parts of a reflex arc is a sine qua non of a reflex. If even one of them is missing (as a result of injury, or for other reasons), the given reflex will be lost.

Reflexes are often studied on so-called spinal frogs under laboratory conditions. In such frogs the brain is either removed or destroyed, but the other parts of the body, including the spinal cord and the nerves emerging from it, are left intact. A spinal frog may live for a

long time and its spinal reflexes may be studied. For example, if the skin is stimulated (by pinching, application of acid, etc.) such a frog responds with a movement of its legs. If the sensory cutaneous nerves or the motor nerves innervating the muscles of the legs are transected,

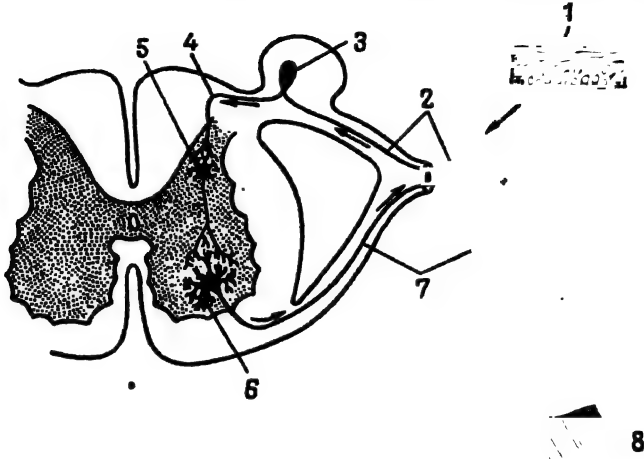


Fig. 123. Diagram of the reflex arc

1—receptor (ending of sensory nerve fibre) in skin; 2—sensory fibre—peripheral process of sensory nerve cell; 3—sensory cell (in nerve ganglion); 4—central process of sensory cell; 5—interneuronal nerve cell (in spinal cord); 6—motor nerve cell (in spinal cord); 7—motor nerve fibre; 8—nerve ending in muscle

there is no reflex in response to the stimulation of the skin. The reflexes are also lost if the nerves are left intact, but the spinal cord (the reflex centres) is destroyed.

#### CHANGES IN EXCITABILITY OF THE CENTRAL NERVOUS SYSTEM

The excitability of the central nervous system, i.e., its ability to become active, varies under different conditions.

One of the conditions for normal activity of the brain and spinal cord is an adequate supply of oxygen to the nerve cells. The cells of the brain and spinal cord consume much more oxygen than the cells of other organs. An inadequate supply of oxygen leads to a decrease in the excitability of the nerve cells and may kill them. It is also clear that changes in the blood circulation in the brain impair the brain's activity because they disturb the normal supply of oxygen and nutrients.

The excitability of the nerve cells is also affected by certain toxic and medicinal substances. Strychnine sharply increases the excitab-

ility of the nervous system. The slightest stimulation of an animal which has been treated with strychnine causes convulsions.

The substances used by doctors to induce anaesthesia cause a sharp decrease in the excitability of the central nervous system.

The changes in the excitability of the different parts of the central nervous system manifest themselves outwardly in altered reflex activity. If the excitability of the central nervous system is increased, even weak stimuli may evoke a strong response reaction of the organism. If the excitability of the central nervous system is decreased, a normal and even a strong stimulus may not evoke a reflex reaction.

### INHIBITION IN THE CENTRAL NERVOUS SYSTEM

The central nervous system reacts not only by excitation, but also by inhibition. Inhibition manifests itself outwardly in a weakening or cessation of reflex activity. Depending on the state of the central nervous system and the character of the stimuli, the nerve impulses transmitted to the brain and spinal cord evoke reflexes in some cases and inhibit them in others. The phenomenon of central inhibition was first established by I. Sechenov in 1862. He stimulated the thalamus in the frog with a crystal of common salt with the result that the reflexes of the spinal cord were inhibited.

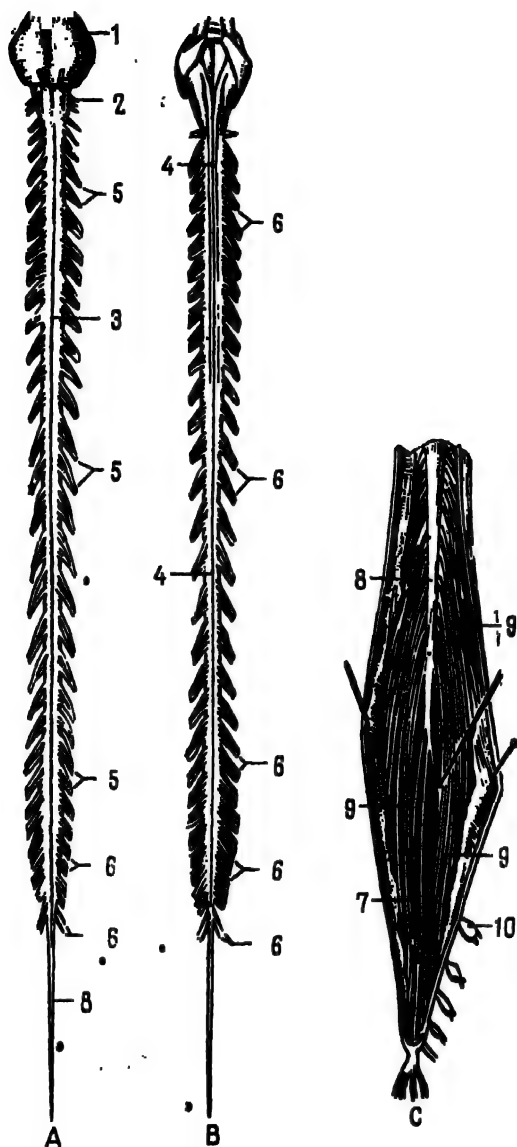
Excitation and inhibition are connected and represent a single process of nervous activity. This unity manifests itself, for example, in the co-ordination of such complex acts as walking, running, etc. In these movements excitation and inhibition alternate in the nerve centres which regulate the work of the flexor and extensor muscles.

Excitation of the centre of the flexor muscles, which causes contraction of the flexors, is followed by inhibition and the flexors relax. At the same time inhibition of the centre of the extensor muscles, which causes relaxation of the extensors, is followed by excitation and the extensors contract. This is again followed by excitation of the centre of the flexors and inhibition of the centre of the extensors, etc.

### SPINAL CORD

#### *Structure of the Spinal Cord*

The spinal cord (medulla spinalis) is located in the vertebral canal. The cord is somewhat flattened anteroposteriorly (Fig. 124). The upper portion passes through the foramen magnum and is continuous with the medulla oblongata (part of the brain), while its lower portion ends at the level of the superior border of the second lumbar vertebra. The lower end of the spinal cord is cone-shaped and is called the *conus medullaris*. In the centre of the spinal cord there is a canal which is actually a narrow slit. Along the anterior and posterior surfaces of



**Fig. 124. Spinal cord**

*A*—anterior view; *B*—posterior view; *C*—terminal part; 1—pons varolli; 2—medulla oblongata; 3—anterior fissure; 4—posterior fissure; 5—anterior roots of spinal nerves; 6—posterior roots of spinal nerves; 7—filum terminale; 8—conus medullaris; 9—nerve roots forming the cauda equina; 10—spinal ganglion

the spinal cord run longitudinal fissures which divide it incompletely into symmetrical halves.

The spinal cord consists of white and grey matter. The grey matter is in the centre of the cord, and the white matter is outside. A horizontal section of the spinal cord shows the grey matter in the form of a butterfly with two anterior projections, the *ventral horns*, and two posterior projections, the *dorsal horns*; the ventral horns are

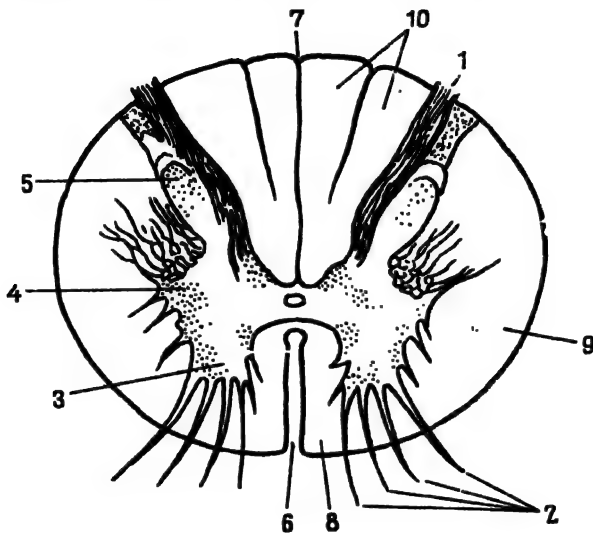


Fig. 125. Transverse section of the spinal cord

1—posterior root; 2—anterior root; 3—ventral horn; 4—lateral horn; 5—dorsal horn; 6—anterior fissure; 7—posterior fissure; 8—ventral funiculus; 9—lateral funiculus; 10—dorsal funiculus

wider than the dorsal horns (Fig. 125). The grey matter surrounding the spinal canal is called the *grey commissure*.

The ventral horns contain motor nerve cells, while the dorsal horns contain internuncial nerve cells which effect communication between other nerve cells, for example between sensory and motor nerve cells. The sensory nerve cells are located not in the spinal cord, but along the sensory nerves, in the intervertebral foramina where they form accumulations called *spinal ganglia*.

Along the thoracic division and the upper part of the lumbar division of the spinal cord, in addition to ventral and dorsal horns, there are also *lateral horns* consisting of sympathetic nerve cells.

The cells of the ventral horns give off processes (axons). These processes form bundles, called *anterior roots* (Fig. 125), which extend to the intervertebral foramina.

Bundles of nerve fibres called *posterior roots*\* extend to the posterior horns of the spinal cord. These roots consist of the processes of the cells of the spinal ganglia.

The anterior roots are motor, and the posterior nerve roots are sensory. In each intervertebral foramen the motor and sensory roots merge and form a spinal nerve. There are 31 pairs of spinal nerves. The portion of the spinal cord corresponding to one pair of spinal nerves is called a *segment*. There are 31 segments: eight cervical, twelve thoracic, five lumbar, five sacral and one coccygeal.

The white matter of the spinal cord is divided in each of its halves into three parts called the *ventral*, *lateral* and *dorsal funiculi*. The funiculi contain nerve fibres which connect the various divisions of the spinal cord with each other and the spinal cord with the brain. The fibres connecting the spinal cord and the brain are grouped in bundles called *nervous pathways* or *tracts*. Some tracts are ascending (sensory), while others are descending (motor).

Below the terminal of the spinal cord in the vertebral canal is the so-called *cauda equina* which consists of roots of the lower spinal nerves (lumbar, sacral and coccygeal).

The spinal cord and the cauda equina are covered with special membranes (see Fig. 139).

### *Functions of the Spinal Cord*

The main functions of the spinal cord are: (1) conduction of excitation (nerve impulses), and (2) reflex activity.

The function of conduction of excitation consists in the following. The spinal cord communicates through nerve fibres, its nervous pathways, with various parts of the brain and through spinal nerves with organs (muscles, skin, blood vessels, etc.). As has already been noted, the spinal cord contains two kinds of nervous pathway—ascending (sensory) and descending (motor). The spinal nerves also contain two types of nerve fibre—sensory and motor.

The nerve impulses transmitted to the spinal cord from the periphery, i.e., from the organs (skin, muscles, etc.), along sensory fibres of the spinal nerves, are then conducted along the ascending nervous pathways to the brain. These impulses (excitation) are perceived by the various parts of the brain. For example, the excitation arising in the receptors of the skin upon stimulation is transmitted to the cerebral cortex. As a result, various sensations, such as heat, cold, pain, etc., arise in the cortex.

Nerve impulses are transmitted from the brain to the spinal cord along the descending pathways and thence along motor fibres of the

\* *Radix* is Latin for root; inflammation of a nerve root is called *radiculitis*.



spinal nerves to the periphery, i.e., the organs. These impulses (excitation) alter the state of various organs; for example, they produce contraction of skeletal muscles, voluntary retention of the urine and faeces, etc.

The reflex activity of the spinal cord is as follows. The spinal cord contains the reflex centres of various functions, such as the centres of muscular activity. Each segment of the spinal cord is concerned with certain groups of muscles. The cervical segments of the spinal cord contain the centres of reflex movements of the diaphragm, muscles of the neck, the shoulder girdle and upper extremities. The thoracic segments contain the centres of the trunk muscles, while the lumbar and sacral segments contain the centres of the pelvic muscles and the muscles of the lower extremities. In examining patients physicians usually examine the so-called tendon reflexes (patellar reflex, the Achilles tendon reflex, etc.). The reflex arcs of these reflexes couple in the spinal cord. The spinal cord also contains the centres of certain other reflexes: the centres of perspiration and the vasomotor centres are located in the thoracic and lumbar divisions, and the centres of urination, defaecation and activity of the sex organs are located in the sacral division.

Let us examine the reflex activity of the spinal cord by using the example of the patellar reflex. Stimulation of the receptors of the quadriceps femoris tendon (for example, by a quick tap with a hammer) gives rise to excitation which is transmitted along sensory nerve fibres to the spinal cord. In the spinal cord the nerve impulses from the sensory nerve cells are transmitted to motor nerve cells. The excitation is then transmitted along motor nerve fibres to the quadriceps femoris muscle which contracts. As a result of this contraction the leg is extended at the knee joint.

Muscle tone is also of a reflex character. It is well known that all muscles are continuously in a state of tension (tone). The muscles, tendons, ligaments and joint capsules have sensory nerve endings called *proprioceptors*. Upon changes in the position of the muscles, joints, and ligaments these receptors are stimulated. The excitation is transmitted along sensory nerves to the spinal cord and thence along motor nerves to the muscles. As a result the muscles are maintained in a continuous state of tension (tone).

Damage to the spinal cord (tumour, injury, etc.) is accompanied by various changes in its functions. If the nervous pathways in various parts of the body are injured, their sensitivity is lost, voluntary muscular contraction is impaired (paralysis), and other phenomena are observed. Damage to centres of the spinal cord leads to loss of reflexes.

It should be remembered that the functions of the spinal cord are regulated by the brain.

## THE BRAIN

The brain (Latin—*cerebrum*, Greek—*encephalon*\*) is located in the cranial cavity. In the adult it weighs an average of 1,280-1,380 g, while in a newly born child it weighs 370-400 g; by the time the child is one year old the weight of the brain has doubled and by the age of four or five years it has trebled. After that the weight of the brain slowly increases until the age of 20.

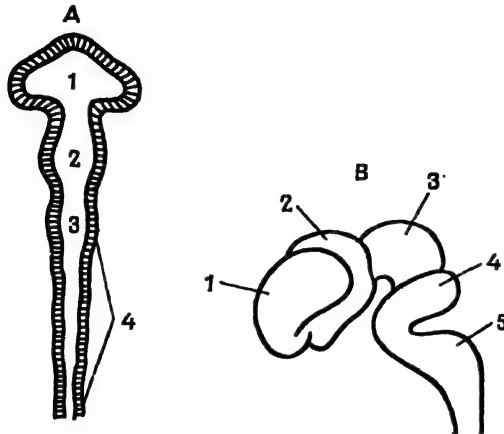


Fig. 126. Development of the brain (diagram)

A—longitudinal section of neural tube showing three brain vesicles (1, 2 and 3); 4—part of neural tube belonging to spinal cord; B—side view of foetal brain—five brain vesicles; 1—first vesicle—endbrain; 2—second vesicle—betweenbrain; 3—third vesicle—midbrain; 4—fourth vesicle—hindbrain; 5—fifth vesicle—medulla oblongata

The brain has a very complex structure. A knowledge of its development helps in the understanding of its structure. The brain develops from the anterior or cerebral part of the so-called neural tube, which separates from the ectodermal neural plate in the early stages of man's embryonic life. During development this part of the neural tube is divided by two constrictions into three dilations—the *anterior*, *middle*, and *posterior primary brain vesicles* (Fig. 126). Later, the anterior and posterior vesicles each divide into two vesicles, resulting in the formation of five secondary brain vesicles. Each brain vesicle develops into a definite part of the brain. It should be noted that not all parts of the brain develop equally: some of them develop faster and become larger than others.

Since the brain develops from five brain vesicles, five parts of the brain are distinguished: (1) endbrain or cerebral hemispheres; (2) betweenbrain consisting of the thalami, geniculate bodies and hypotha-

\*Inflammation of the brain is called *encephalitis*.

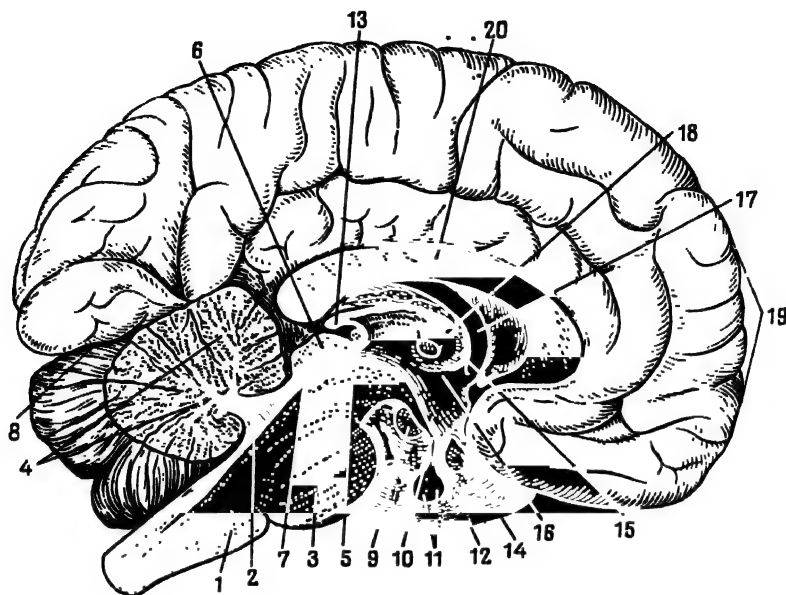


Fig. 127. Sagittal section of the brain

1—medulla oblongata; 2—fourth ventricle; 3—pons varolii; 4—cerebellum; 5—cerebral peduncle; 6—corpora quadrigemina; 7—cerebral aqueduct; 8—transverse cerebral fissure (between cerebral hemispheres and cerebellum); 9—mammillary body; 10—tuber cinereum; 11—hypophysis; 12—infundibulum; 13—pineal gland; 14—optic chiasm; 15—interventricular foramen (between third and lateral ventricles); 16—hypothalamic sulcus; 17—fornix cerebri; 18—thalamus; 19—cerebral hemisphere; 20—corpus callosum

larus; (3) midbrain which includes the corpora quadrigemina and the cerebral peduncles; (4) hindbrain which includes the cerebellum and the pons; (5) medulla oblongata (see Fig. 127). The last three parts of the brain (except the cerebellum) are united under the common name of the *brain stem* (Fig. 128).

Inside the brain there are four intercommunicating cavities called *ventricles*; two *lateral ventricles* are located in the cerebral hemispheres, the *third ventricle* is situated in the betweenbrain, and the *fourth ventricle* is a common cavity of the hindbrain and the medulla oblongata. The ventricles contain cerebrospinal fluid.

The different parts of the brain are developed unequally and have different functions. In the human brain the cerebral hemispheres dominate the other parts of the central nervous system. They make up about 80 per cent of the total brain weight. As a result of the long process of evolution, the cerebral hemispheres and cerebral cortex of man have acquired an extremely complex structure.

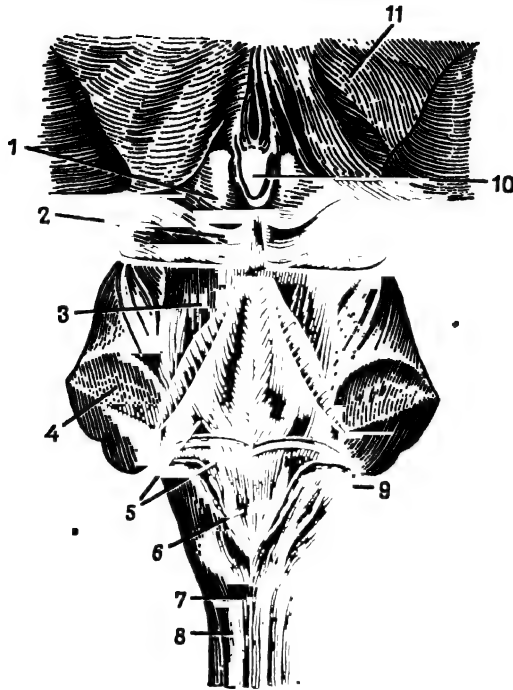


Fig. 128. Posterior view of the brain stem (the cerebellum is removed)  
 1—superior colliculus; 2—inferior colliculus; 3—cerebellar peduncle to the inferior colliculi;  
 4—cerebellar peduncle to the pons; 5—rhomboid fossa; 6—location of the nucleus of the  
 twelfth pair of cranial nerves; 7—fasciculus gracilis; 8—fasciculus cuneatus; 9—cerebellar  
 peduncle to the medulla oblongata; 10—pineal gland; 11—thalamus

### *Medulla Oblongata and Pons Varolii*

The **medulla oblongata** is situated in the sloping part of the cranial cavity; below it is the spinal cord, and above is the pons varolii (Fig. 129). Along the anterior surface of the medulla oblongata runs a fissure with two eminences—a *pyramid* and an *olive*—on each side. On the posterior surface there is a groove and two posterior funiculi which are a continuation of similar funiculi of the spinal cord. Two bundles—fasciculi—are distinguished in each posterior funiculus; a *fasciculus gracilis* (medial) and a *fasciculus cuneatus* (lateral).

The medulla oblongata consists of grey and white matter. The grey matter forms separate accumulations of nuclei inside the white matter.

The **pons varolii** is a thickening located above the medulla oblongata (see Fig. 129). Above the pons are the *cerebral peduncles*. The

lateral parts of the pons are constricted and are called the *middle cerebellar peduncles*; they connect the pons with the cerebellum. Like the medulla oblongata the pons consists of grey and white matter. The grey matter forms accumulations of cells, called *nuclei*, inside the white matter. Most nuclei of the medulla oblongata and of the pons are nuclei of cranial nerves. The processes of the cells of these nuclei emerge from the brain and form the cranial nerves. The white

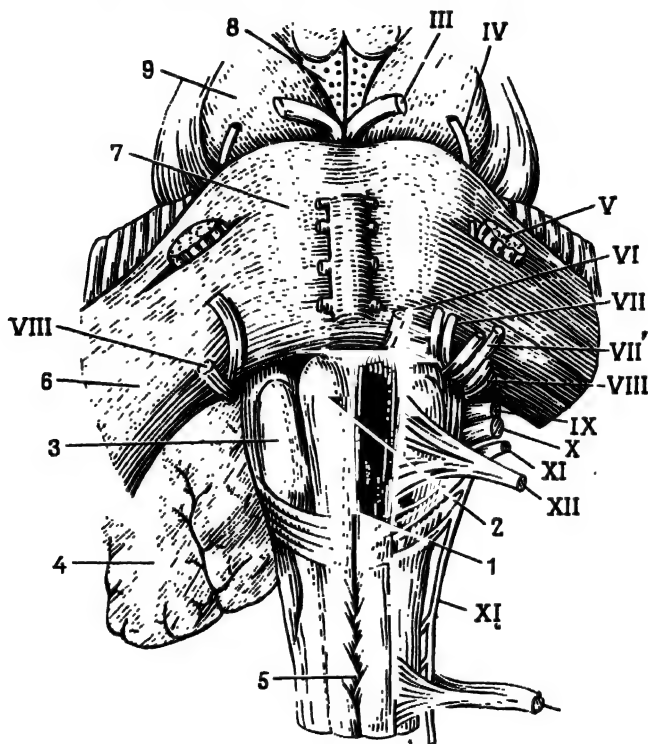


Fig. 129. Anterior view of the brain stem

1—anterior median fissure of medulla oblongata; 2—pyramid of medulla oblongata; 3—olive; 4—cerebellum; 5—decussation of pyramids and point where medulla oblongata becomes continuous with spinal cord; 6—middle cerebellar peduncle (brachium pontis); 7—pons varolii; 8—interpeduncular fossa; 9—cerebral peduncle; III, IV, V, VI, VII, VIII, IX, X, XI, and XII—corresponding pairs of cranial nerves; VII'—intermedius nerve; C—first spinal nerve

matter of the medulla oblongata and the pons contains the nerve fibres of the nervous pathways which are located in the spinal cord. It also contains the fibres which connect the nuclei of the cranial nerves with the other parts of the brain and with the spinal cord. The posterior surface of the medulla oblongata and the pons forms the so-called *rhomboid fossa* which is the floor of the fourth ventricle.

The *fourth ventricle* (see Fig. 127) is a small cavity with two walls, called the floor (rhomboid fossa) and the roof. The medullary substance in the region of the rhomboid fossa contains the nuclei of the pons and of the medulla oblongata. The roof is formed by thin plates of medullary substance adhering to the cerebellum. The fourth ventricle communicates with the canal of the spinal cord, the third ventricle and the subarachnoid space.

**Functions of the medulla oblongata and of the pons.** The medulla oblongata and the pons, like the spinal cord, have two functions: one is a reflex function and the other is the conduction of nerve impulses.

The **reflex function** is due to the fact that these structures contain the nuclei of the cranial nerves and the centres of various reflexes. The nuclei of 8 pairs of cranial nerves, from the fifth to the twelfth, are located in the rhomboid fossa.

The medulla oblongata contains vitally important centres, including the above-mentioned centres of cardiac activity and respiration. Each centre is an accumulation of nerve cells regulating the activity of certain organs. When a centre is stimulated nerve impulses are transmitted along motor nerves to an organ and either excite it to activity or inhibit its functioning. For example, the centre of cardiac activity, which is located in the medulla oblongata, sends impulses to the heart along the vagus nerve and exerts an inhibitory influence on the heart. The impulses transmitted to the heart along the sympathetic nerve accelerate its activity.

The medulla oblongata also contains the vasomotor centre which when excited produces changes in the lumens of the blood vessels. This centre is closely connected with the vasomotor centres in the spinal cord which constrict the blood vessels. The medulla oblongata also contains the centres of many digestive reflexes (salivation, secretion of gastric and pancreatic juices, deglutition, etc.) and defence reflexes (coughing, vomiting, etc.). These centres communicate with the corresponding organs through the cranial nerves.

The medulla oblongata is a vitally important part of the central nervous system. Disturbances in the medulla oblongata may lead to death from respiratory and cardiac arrest.

It should be noted that the reflexes effected through the medulla oblongata and the pons are more complex than those effected through the spinal cord. The medulla oblongata and pons simultaneously regulate many functions of the organism, both directly and through the centres of the spinal cord. The functions of the centres of the medulla oblongata may be illustrated by that of the vomiting centre. Excitation arises in the vomiting centre as a result of stimulation of the receptors in the digestive tract or the meninges. This excitation is transmitted from the medulla oblongata (along the vagus

nerve) directly to the muscles of the digestive tract, and also to the centres of the spinal cord which regulate the functions of the striated muscles of the abdominal wall and diaphragm and the smooth muscles of the intestines, stomach and oesophagus. The excitations arising in these centres co-ordinate the work (contraction and relaxation) of the different muscles involved in the act of vomiting. First there are antiperistaltic movements of the intestines and a relaxation of the pyloric sphincter of the stomach, so that the intestinal contents are ejected into the stomach. This is followed by a strong contraction

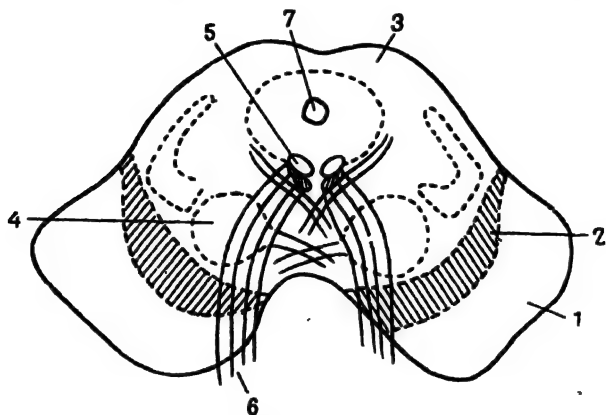


Fig. 130. Transverse section of the midbrain (diagram)

1—cerebral peduncle; 2—substantia nigra; 3—corpora quadrigemina; 4—red nucleus; 5—nucleus of third pair of cranial nerves; 6—third cranial nerve; 7—cerebral aqueduct

of the diaphragm and abdominal muscles (the muscles of the oesophagus are at this time relaxed) with the result that the stomach is compressed and its contents are ejected through the oesophagus and mouth.

The conduction function of the medulla oblongata and the pons varolii is made possible by the ascending and descending nervous pathways (tracts). Impulses are transmitted along the nerve fibres of these tracts from the spinal cord to the brain and from the brain to the spinal cord.

The functions of the medulla oblongata and the pons are influenced by the cerebral cortex and other parts of the brain.

### Midbrain

The midbrain (mesencephalon) lies anteriorly of the pons (Fig. 130). It contains two cerebral peduncles and the corpora quadrigemina. The cavity of the midbrain is a narrow cleft and is called the cerebral aqueduct; it connects the third and fourth ventricles. The cerebral

peduncles consist of grey and white matter. The grey matter is on the inside and consists of nuclei. The largest of these are the *black substance* (substantia nigra) and the *red nucleus* (nucleus ruber) (Fig. 130). The red nucleus is paired. The cerebral peduncles also contain the nuclei of the third and fourth pairs of cranial nerves. The red nuclei give rise to the descending tract which connects them with the ventral horns of the spinal cord (rubrospinal tract).

The white substance of the cerebral peduncles consists of nerve fibres of the ascending (sensory) and descending (motor) tracts.

The *corpora quadrigemina* are four eminences, or *colliculi*, two superior and two inferior. The colliculi contain accumulations of nerve cells—nuclei. Some fibres of the optic tract extend to the superior colliculi and some fibres of the auditory tract extend to the inferior colliculi. The nuclei of the corpora quadrigemina give off nerve fibres to the ventral horns of the spinal cord.

**Functions of the midbrain.** The midbrain performs various functions. The nuclei of the corpora quadrigemina are centres of the so-called orientation reflexes, i.e., they regulate the complex movements of the body in response to sudden optic and acoustic stimuli.

The arc of the pupillary reflex (constriction of the pupil in response to bright light) closes in the midbrain. The nuclei of the cerebral peduncles participate in regulating and distributing muscular tone: they regulate the degree of tension of the various groups of muscles, such as the flexors and extensors. It has been established in experiments on animals that removal of the cerebral hemispheres, leaving the midbrain and underlying parts of the central nervous system intact, preserves the ability of the animal to rise and maintain its posture. Patients suffering from disturbances of the midbrain (tumours, haemorrhages, etc.) exhibit various changes in muscle tone, particularly the phenomenon of decerebrate rigidity which manifests itself in a sharply increased tone of the extensors of the limbs, trunk and neck. This phenomenon is associated with a disturbance in the regulatory influences of the nuclei of the midbrain and the reticular formation on the muscles. Nerve impulses are transmitted from the midbrain to the muscles through the spinal cord. Impulses from the cerebellum, the nuclei of the cerebral hemispheres and the cerebral cortex are in their turn transmitted to the nuclei of the cerebral peduncles. These impulses exert a regulatory influence on the activities of the nuclei of the midbrain.

### *Reticular Formation*

The brain stem contains the so-called reticular formation. This formation consists of a large number of nerve cells and nuclei arranged in the form of a cord and interconnected by a network of nerve fibres.



The reticular formation communicates with the other parts of the central nervous system (cerebral cortex, spinal cord, cerebellum, etc.) through the ascending and descending tracts. Considerable attention is now being paid to studies of the structure and function of the reticular formation. It has been established that this formation exerts an influence on various functions of the organism. The influence is exerted not directly, but through other parts of the brain and spinal cord, and alters their functional state. For example, the impulses reaching the cerebral cortex from the reticular formation enhance the activity of the cortex. The state of sleep or waking in large measure also depends on the reticular formation. The reticular formation influences the reflex activity of the spinal cord.

The activity of the reticular formation is in its turn maintained by the influences of the cerebral cortex and other parts of the nervous system and by humoral factors. For example, patients who have fainted are given to inhale aromatic spirits of ammonia. This stimulates the endings of the trigeminal nerve, the impulses are transmitted to the reticular formation and its activity is intensified. Adrenalin (hormone) stimulates the functional state of the reticular formation.

Many medicinal substances (aminazine, luminal, etc.) apparently act through the reticular formation.

Pathologic processes in the reticular formation may be the cause of various disturbances in the organism (pathologic sleep, intractable insomnia, etc.).

### *Betweenbrain*

The **betweenbrain** (diencephalon) is located in front of the cerebral peduncles (see Fig. 127). It includes the two thalami, the hypothalamus, the two pairs of geniculate bodies (lateral and medial), the hypophysis and the epiphysis.

The **thalami** are the largest structures of the betweenbrain. They consist mainly of nerve cells which form nuclei.

The **hypothalamus** is located below the thalami. The largest structures of this region are the *tuber cinereum* and the *mammillary bodies*. They contain accumulations of nerve cells—nuclei. The inferior portion of the tuber cinereum is continuous with the hypophysis.

The **geniculate bodies** are situated behind the thalami and contain accumulations of nerve cells.

Between the two thalami is a slit-like cavity, the **third ventricle**, which communicates through two interventricular orifices with the lateral ventricles of the cerebral hemispheres and through the cerebral aqueduct with the fourth ventricle.

**Functions of the betweenbrain.** The thalami are intermediate (subcortical) sensory centres. The nervous pathways along which excitation is transmitted from all the receptors of the human body extend

to the thalami. The thalami communicate through nerve fibres with various parts of the cerebral cortex. Nerve impulses conducted to the cerebral cortex are first transmitted to the thalami, the subcortical sensory centres.

The thalami also communicate with the *globi pallida*. These structures are located laterally of the thalami and are subcortical motor centres. Damage to the thalami causes various disturbances in sensitivity (reduction or total absence of some particular form of sensitivity, and sometimes spontaneous "thalamic pains").

The hypothalamus contains vegetative centres which regulate metabolism, heat production and heat loss, arterial pressure, cardiac activity and other vegetative functions. The hypothalamus also exerts a regulatory influence through the hypophysis on the activity of the endocrine glands. Damage to the hypothalamus is characterized by disturbances in thermoregulation, in protein, carbohydrate, fat, water and salt metabolism, various endocrine disorders, and other changes.

The lateral geniculate bodies are intermediate (subcortical) visual centres; the medial geniculate bodies are auditory centres. The impulses transmitted from the visual and auditory sense organs to the cerebral cortex pass through the geniculate bodies so that injuries to the geniculate bodies cause disturbances in vision and hearing.

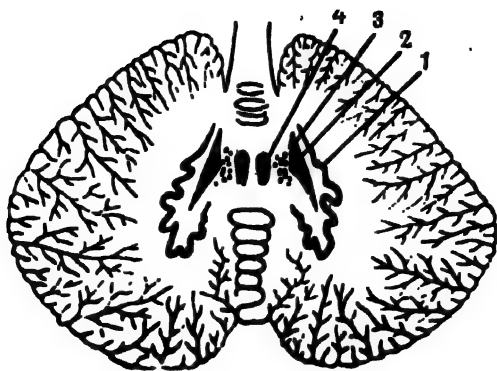
### *Cerebellum*

The **cerebellum** is located behind the medulla oblongata and the pons (see Fig. 127). It has two lobes and a middle part called the *vermis*. It consists of grey and white matter. The grey matter forms a continuous outer layer, the cortex of the cerebellum. Under the cortex is the white matter which contains the nuclei of the cerebellum (Fig. 131). The largest of these is the dentate nucleus.

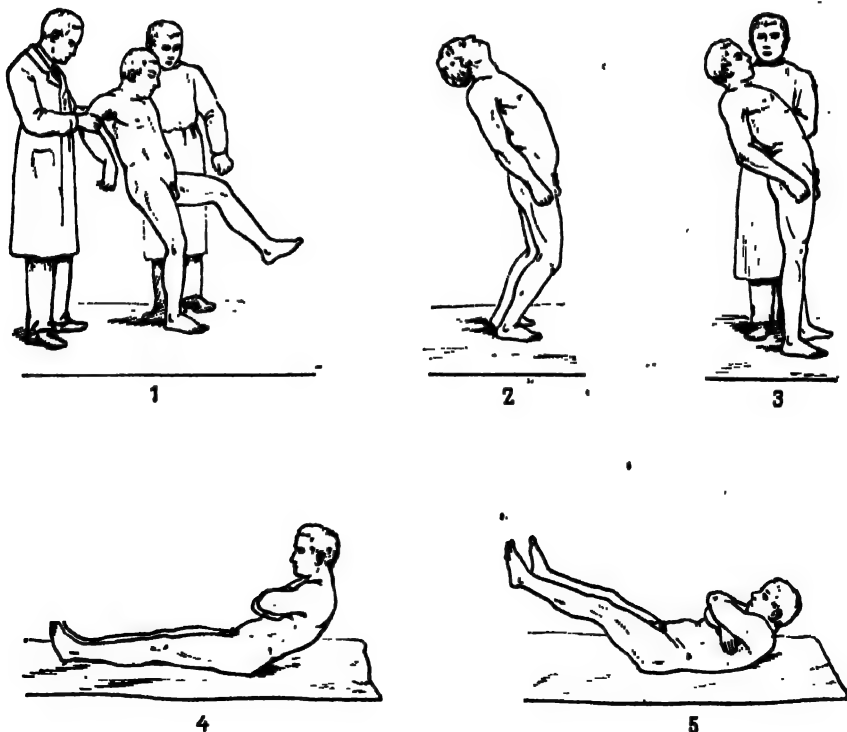
The cerebellum communicates with other parts of the brain through nerve fibres which form roller-like thickenings. There are three pairs of thickenings (cerebellar peduncles): the superior, which connects the cerebellum with the midbrain, the middle which connects the cerebellum with the pons, and the inferior, which connects the cerebellum with the medulla oblongata (see Fig. 128).

**Functions of the cerebellum.** The cerebellum is concerned with co-ordination, distinctness and smoothness of movements. It also plays an important part in maintaining bodily balance in space and affects the tone of the muscles. Damage to the cerebellum causes disturbances in walking (Fig. 132); movements become unco-ordinated and sweeping (ataxia), "cerebellar" tremor appears, the speech is affected and, in severe cases, the patients are unable to walk.

The activities of the cerebellum are of a reflex character. The cer-



**Fig. 131. Horizontal section of the cerebellum (diagram)**  
 1—dentate nucleus; 2, 3 and 4—other cerebellar nuclei



**Fig. 132. Motor disorders caused by cerebellar lesions**  
 1—gait of patient with cerebellar disorders; 2—normal backward bend of body; 3—backward bend of body of patient with cerebellar lesions (patient does not synkinetically bend legs in the knee joints); 4—normal sitting up; 5—sitting up in cases of cerebellar lesions

ebellum receives impulses from the muscles along ascending (spino-cerebellar) tracts and transmits impulses to the muscles along descending tracts (mainly through the red nuclei of the cerebral peduncles). The cerebellum not only participates in regulating the co-ordinations of movements, but also influences the vegetative functions of the organism. For example, in experiments on animals conducted in L. Orbeli's laboratory stimulation of the cerebellum resulted in changes similar to those produced by the influence of the sympathetic division of the vegetative system, i.e., rise in blood pressure, change in cardiac activity, dilation of the pupils, etc. The activities of the cerebellum are influenced by the cerebral cortex.

### Cerebral Hemispheres

There are two cerebral hemispheres—right and left. They consist of grey and white matter. The grey matter forms the outer layer, called the **cerebral cortex**. Inside this is the white matter, containing various accumulations of nerve cells which make up the *nuclei of the cerebral hemispheres (nuclei of the base of the brain or subcortical ganglia)*. The largest nuclei are the *caudate nucleus* and the *lenticular nucleus* (Fig. 133), which together make up the so-called *corpus striatum*. The lenticular nucleus is divided by a layer of white matter into two parts: the *putamen* and the *globus pallidus*. Each hemisphere is divided into *frontal, parietal, temporal* and *occipital lobes*, and a lobule called the *insula*. On the surface of the hemispheres there are *fissures* or *sulci*, and between them eminences called *convolutions* or *gyri* (Fig. 134). The fissure between the frontal and parietal lobes is called the *central sulcus*, and the fissure between the parietal and occipital lobes is called the *parieto-occipital sulcus*. The temporal lobe is separated from the frontal and parietal lobes by the lateral cerebral fissure which contains the *insula*. The frontal lobe has a precentral fissure and two frontal fissures, called the *superior* and *inferior sulci*. The *ascending frontal gyrus* lies between the central and precentral sulci. The frontal sulci separate the *inferior, middle* and *superior frontal gyri*.

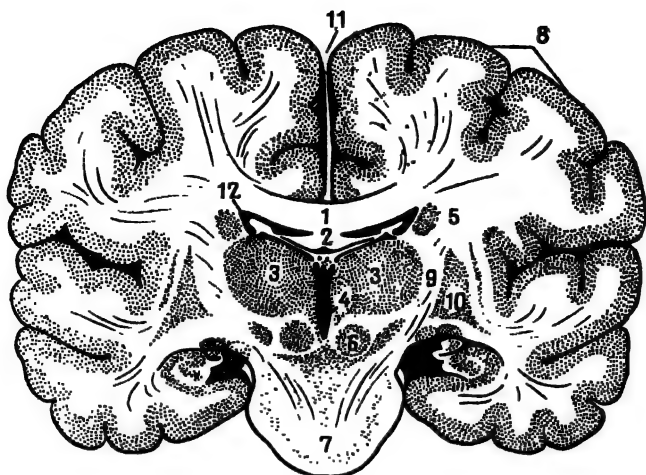
The parietal lobe carries *postcentral* and *intraparietal sulci*, the *ascending parietal gyrus* and the *superior* and *inferior parietal lobules*.

In the temporal lobe four fissures separate the *superior, middle, inferior temporal, fusiform* and *hippocampal gyri*.

The occipital lobe has a *lingual gyrus*, a *cuneus* and other *gyri* and *fissures*.

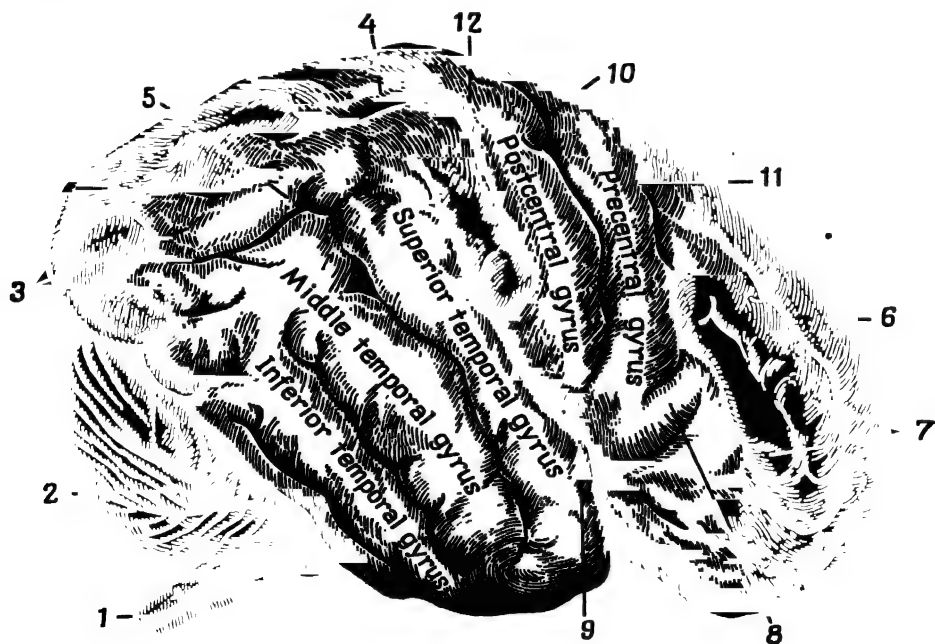
The two hemispheres are linked by the *corpus callosum* which consists of nerve fibres.

The inferior surface of the hemispheres and the brain stem are called the *base of the brain*.



**Fig. 133. Frontal section of the brain**

1—corpus callosum; 2—fornix cerebri; 3—thalamus; 4—third ventricle; 5—caudate nucleus; 6—red nucleus; 7—pons varolli; 8—cerebral cortex; 9—internal capsule; 10—lenticular nucleus; 11—longitudinal fissure of cerebrum (interhemispheric fissure); 12—lateral ventricle



**Fig. 134. Gyri and sulci of the cerebral hemispheres**

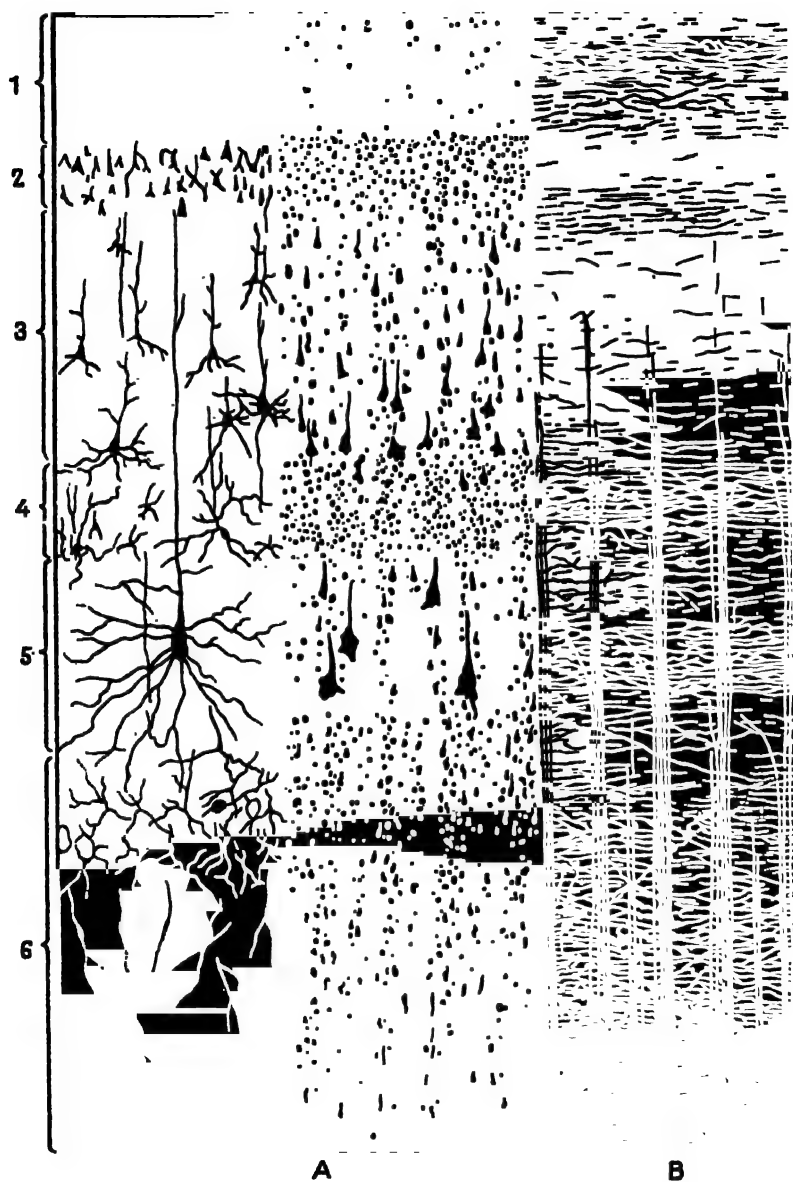
1—spinal cord; 2—cerebellum; 3—gyri in occipital lobe; 4—superior parietal lobule; 5—inferior parietal lobule; 6—superior frontal gyrus; 7—middle frontal gyrus; 8—inferior frontal gyrus; 9—lateral cerebral fissure; 10—central sulcus; 11—precentral fissure; 12—postcentral sulcus

Each hemisphere has a **lateral ventricle**. A lateral ventricle is an irregularly shaped cavity consisting of four parts: the central part (in the parietal lobe), the anterior cornu (in the frontal lobe), the inferior cornu (in the temporal lobe) and the posterior cornu (in the occipital lobe). The walls of the lateral ventricles are formed by the substance of the hemispheres. The lateral ventricles, like the other cerebral ventricles, contain cerebrospinal fluid. Each lateral ventricle communicates with the third ventricle.

The **nuclei of the cerebral hemispheres** are subcortical motor centres. Together with the red nuclei of the cerebral peduncles and certain other parts of the brain they compose the so-called *extrapyramidal system*. This system ensures the automatism of movements, i.e., the contraction of muscles in a definite combination and sequence in running, walking, etc. Lesions in the extrapyramidal system are characterized by various involuntary compulsory movements or, on the contrary, by rigidity and little movement. As was noted above, the nuclei of the hemispheres, particularly the globus pallidus, are connected with the subcortical sensory centres, the *thalami*. Nerve impulses may be transmitted from the cells of the thalami to the cells of the globus pallidus and thence to the brain stem and the spinal cord.

The **white matter of the cerebral hemispheres** consists of nerve fibres which connect various parts of the central nervous system. Some fibres effect communication between the two hemispheres, others connect various parts of the same hemisphere, and still others connect the cerebral cortex and the underlying parts of the central nervous system. The nerve fibres connecting the cerebral cortex with other parts of the central nervous system are called projection fibres. They form a layer of white matter, called the *internal capsule* (*capsula interna*), which lies between the caudate nucleus and the thalamus on one side, and the lenticular nucleus on the other side (see Fig. 133). The fibres of the internal capsule make up part of the tracts which extend from the hemispheres to the cerebral peduncles and then the pons, the medulla oblongata and the spinal cord. Impulses are transmitted to the cerebral cortex along some of the tracts (ascending tracts), and from the cortex along others (descending tracts).

The **cerebral cortex** is a layer of grey matter 2-4 mm thick. Its total surface area, including the sulci and the gyri, is about 2,200 sq cm. The cortex has a complex histological structure. Under the microscope several layers of nerve cells and nerve fibres can be seen (Fig. 135). The cells differ in shape, size and arrangement. The cortex contains about 14,000 million nerve cells. The Russian scientist V. Betz (1874) first drew attention to the complex structure of the cerebral cortex. He established that each portion of the cerebral cortex differs in structure from the others, and also described certain forms of nerve cells in the cortex.



**Fig. 135. Structure of the cerebral cortex**

**A—arrangement of nerve cells in cortex. Figures 1, 2, 3, 4, 5 and 6 indicate six layers of cells;  
B—arrangement of nerve fibres in cortex**

The cerebral cortex differs in different animals. It arose later in the process of evolution than the other parts of the nervous system. It appeared first in reptiles, and gradually became more complex in each succeeding class of vertebrates. The structure of the cortex is most complex in the higher mammals. The cerebral hemispheres and cortex are particularly highly developed in man. As the cerebral cortex has developed it has increased in importance as the highest part of the nervous system regulating the functions of the organism and linking the organism with the external environment.

**Role of the different regions of the cerebral cortex.** I. Pavlov regarded the cerebral cortex as a complex system of analysers in which the stimuli are analysed and synthesized. All areas of the cortex are interconnected and the activity of each depends on the state of the entire cortex. However, the different regions differ in function and structure. I. Pavlov recognized the existence in the cortex of "receptive areas", which are special regions for the main external receptors. He named these areas **analysers** (or cerebral ends of analysers), e.g., the visual analyser, auditory analyser, motor analyser, etc. Each analyser in the cerebral cortex consists of a central part or nucleus in which the highest analysis or synthesis takes place, and a peripheral part in which simpler analysis and synthesis are carried out. The area of each analyser in the cortex is not strictly defined and appears to overlap other areas. This was demonstrated in experiments in which various parts of the cerebral hemispheres of animals were removed. For example, if the temporal lobe containing the central part of the auditory analyser is removed, a dog will not discriminate complex sounds, but will retain its ability to distinguish simple sounds. Some cells of the auditory analyser are apparently located in other parts of the hemispheres.

The location of the main analysers is examined below (see Fig. 134).

1. The **motor analyser** is located mainly in the ascending frontal gyrus (frontal lobe). Here the proprioceptive stimuli are perceived and analysed and temporary connections, reflex muscular movements, are formed. The superior part of the gyrus contains groups of nerve cells which are functionally connected with the muscles of the lower extremities. The inferior part of the gyrus contains nerve cells concerned with the muscles of the head, and the middle parts contain nerve cells connected with other groups of muscles.

2. The **analyser of cutaneous sensitivity** (pain, thermal, etc.) is situated in the ascending parietal gyrus (parietal lobe).

3. The **analyser of olfaction** is located in the inner part of the hippocampal gyrus (temporal lobe). It is believed that the taste analyser is also located there.

4. The **auditory analyser** is situated in the superior temporal gyrus.

5. The **visual analyser** is situated in the occipital lobe.



The **function of speech** is found only in man; it requires the participation of the entire cortex, but is mainly associated with certain areas. These areas include the posterior part of the inferior frontal gyrus which contains the motor speech analyser (in right-handed people this lies on the left, in left-handed people, on the right). Lesions in this analyser are characterized by disorders of oral speech. Damage to the other cerebral areas which contain analysers leads to disturbances in the corresponding functions.

It should be remembered that thinking is associated with the activity of the entire cerebral cortex and not only with the function of its separate areas.

### NERVE TRACTS

The cerebral cortex communicates with the other parts of the nervous system through nervous pathways or tracts. Nerve impulses pass along sensory or ascending tract to the cerebral cortex, and along motor or descending tracts from the cortex. The most important sensory and motor tracts are shown in Fig. 136.

**Pain and thermal sensitivity tracts** (see Chapter 10 "Sense Organs"). The sensory fibres along which impulses are transmitted from the pain and thermal receptors of the skin are parts of spinal nerves; they make contact with the cells of the dorsal horns in the spinal cord. The processes of the cells of the dorsal horns form a bundle called the **spinothalamic tract**. In the spinal cord the fibres of this tract cross over to the opposite side, pass along the lateral funiculi, and go through the medulla oblongata, the pons varolii and the cerebral peduncles to the thalamic cells. The processes of the thalamic cells extend in the internal capsule to the cortex in the region of the ascending parietal gyrus (the area of the cutaneous sensitivity analyser). Since the fibres of the spinothalamic tract cross over to the opposite side in the spinal cord, the nerve impulses from the skin of the right half of the body are transmitted to the cortex of the left cerebral hemisphere, and those from the skin of the left half of the body pass to the cortex of the right cerebral hemisphere.

**Music-articular sensitivity tract.** The sensory nerve fibres which pass impulses from the receptors in the muscles, joints and ligaments enter the spinal cord with the spinal nerves. These fibres do not terminate in the spinal cord but ascend in the fasciculi gracilis and cuneatus along the dorsal funiculi into the medulla oblongata where they contact the cells of special nuclei. The cells of these nuclei give off nerve fibres which cross over to the other side in the medulla oblongata and ascend through the pons varolii and cerebral peduncles to the thalami. The processes of the thalamic cells in their turn traverse the internal capsule to the cerebral cortex (area of the motor analyser).

There are also musculo-articular sensitivity tracts extending to the cerebellum (spinocerebellar tracts).

**Motor tracts.** One of the most important tracts along which impulses are transmitted from the cerebral cortex is the pyramidal or

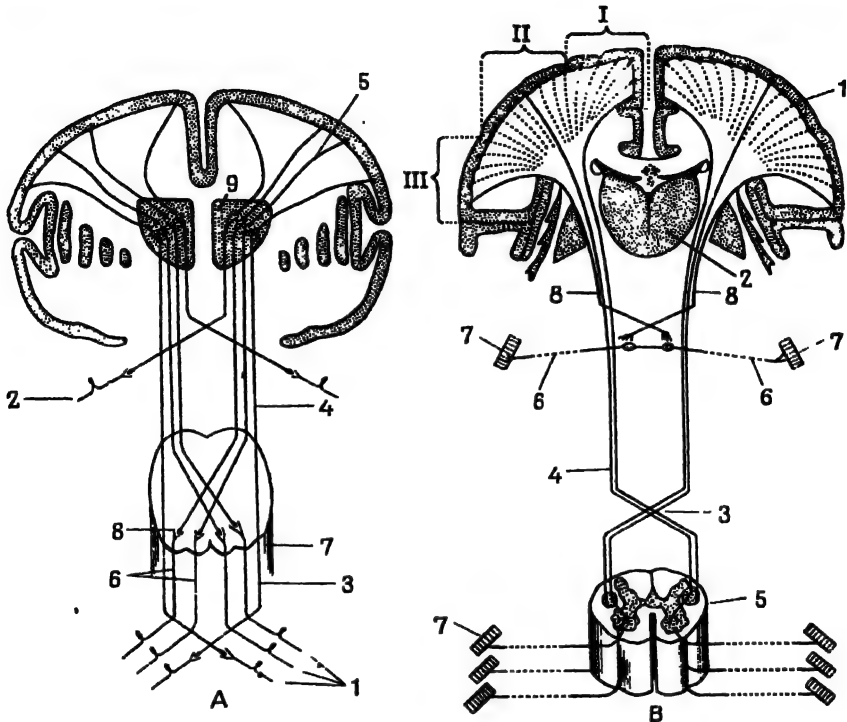


Fig. 136. Conduction pathways (nerve tracts)

**A—sensory tracts:** 1—sensory fibres of spinal nerves; 2—sensory fibres of cranial nerves; 3, 4 and 5—spinothalamic tract (conduction pathway of pain and temperature sensitivity); 6—fasciculus gracilis and fasciculus cuneatus (conduction pathways of muscle and joint sensitivity); 7—medulla oblongata; 8—nuclei of fasciculus gracilis and fasciculus cuneatus; 9—thalamus; **B—motor tracts:** I, II and III—motor area of the cortex; 1—cerebral cortex; 2—thalamus; 3—decussation of pyramidal tract; 4—pyramidal tract; 5—part of spinal cord; 6—motor cranial nerve; 7—muscles; 8—corticospinal tract

**corticospinal tract.** This tract arises from the pyramidal cells of the anterior ascending gyrus of the cerebral hemispheres. The fibres of the corticospinal tract traverse the internal capsule to the cerebral peduncles, the pons varolii and the pyramids of the medulla oblongata. In the inferior portion of the medulla oblongata the greater part of the fibres of this tract decussate, i.e., cross over from one side to

the other and descend into the lateral funiculi of the spinal cord; the remaining fibres descend along its ventral funiculi. In the spinal cord the fibres of the corticospinal tract extend to the cells of the ventral horns. Nerve impulses from the cells of the ventral horns are transmitted along motor fibres of the spinal nerves to the muscles.

Since the fibres of the corticospinal tract cross over to the opposite side, nerve impulses are transmitted along this tract from the cortex of the right hemisphere to the muscles of the left half of the body, and from the cortex of the left hemisphere to the muscles of the right half of the body.

The **corticobulbar** or **corticonuclear tract**, whose fibres extend to the motor nuclei of the cranial nerves, begins at the inferior portion of the anterior ascending gyrus of the cerebral hemispheres. Nerve impulses from the cells of these nuclei are transmitted along motor fibres of the cranial nerves to the corresponding muscles.

### HIGHER NERVOUS ACTIVITY

I. Pavlov called the function of the cerebral cortex higher nervous activity. It is intimately connected with the adjacent subcortical ganglia (adjacent subcortex). The function of the cortex, like that of the other parts of the nervous system, is of a reflex character. This was suggested by I. Sechenov in his book *Reflexes of the Brain* published in 1863. However, an objective study of the processes operating in the cerebral cortex became possible only after I. Pavlov had discovered conditioned reflexes and had established that they form the basis of higher nervous activity in animals.

The work of the parts of the nervous system other than the cortex and adjacent subcortical ganglia is called lower nervous activity. It is based on the principle not of conditioned, but of unconditioned reflexes.

**Unconditioned reflexes** are inborn reflexes transmitted through heredity. Complex inborn reflexes are also called **instincts**. The unconditioned reflexes include the pupillary, sucking, swallowing and tendon reflexes and many others. The reflex arcs of the unconditioned reflexes are constant, i.e., they include definite receptors, sensory nerves, centres and motor nerves. Unconditioned reflexes arise in response to definite stimuli; the unconditioned salivary reflex manifests itself only in response to the action of food on the taste papillae (see Fig. 137). The resulting excitation is transmitted along sensory (gustatory) nerves to the salivary centre which is located in the medulla oblongata. From the medulla oblongata nerve impulses pass along motor (secretory) nerves to the salivary glands. The centres of the different unconditioned reflexes are located in different parts

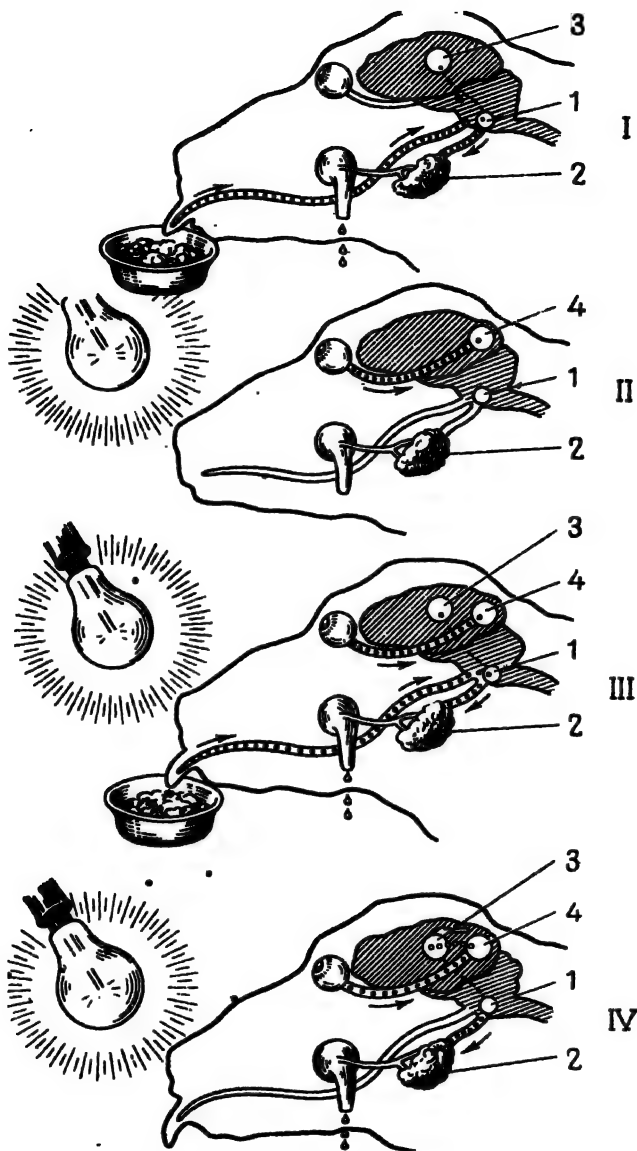


Fig. 137. Diagram showing formation of conditioned reflex

*I*—unconditioned salivary reflex; *II*—action of conditioned stimulus (light from electric bulb) and appearance of a focus of excitation in the visual area of the cortex; *III*—reinforcement of the conditioned stimulus with an unconditioned stimulus; the cortex simultaneously has two foci of excitation, one in the visual area and the other in the food area; *IV*—formation of conditioned reflex; arrow indicates resultant temporary connection between the visual and food areas in the cortex; 1—salivary centre in medulla oblongata; 2—salivary gland; 3—focus of excitation in food area; 4—focus of excitation in visual area

of the spinal cord and brain. The work of various organs and systems is continuously regulated and co-ordinated, and the existence of the organism is maintained by unconditioned reflexes. Unconditioned reflexes can adapt the organism only to the particular changes in the environment which have been acting continuously on many generations of the given species of animal.

**Conditioned reflexes** are acquired; they arise during the lifetime of the animal or man. They are strictly individual and are not constant, i.e., they may disappear and appear again. Conditioned reflexes arise in response to any stimuli—conditioned stimuli or signals. For example, if the unconditioned food reflex is brought about only by the action of food on the taste papillae, the conditioned food reflex arise at the sight and odour of food (without eating) and in response to any other stimulus formerly coinciding with the time of eating. The reflex arcs of conditioned reflexes close in the cerebral cortex and are of a temporary character.

Conditioned reflexes are temporary connections of the animal organism with its environment. By means of these reflexes the organism adapts itself to the constantly changing conditions of the environment and "...the complex relations of the integral organism with the external and internal environment and the fine equilibration of the organism with its surroundings... are ensured" (K. Bykov). Functional connections between conditioned and unconditioned reflexes are established in the living organism.

Conditioned reflexes are formed under definite conditions, and are based on unconditioned reflexes. *The action of the conditioned stimulus must therefore necessarily coincide in time with the action of the unconditioned stimulus.* In other words, the conditioned stimulus must be reinforced by an unconditioned stimulus. For example, the conditioned-reflex secretion of saliva in response to the sight and odour of food is the result of these stimuli coinciding with the intake of food. It is also necessary for *the beginning of the action of the conditioned stimulus to occur just before the action of the unconditioned stimulus.* A conditioned reflex is formed *if the action of the conditioned and unconditioned stimuli coincides several times.* Let us assume that an animal must be given a conditioned salivary reflex to an optic stimulus. The light of an electric bulb is used as a conditioned stimulus (see Fig. 137). The unconditioned stimulus is the food which always brings about secretion of saliva. The electric light is turned on a few seconds before the animal is fed and is not turned off until the end of the feeding. If this procedure is repeated several times, a conditioned salivary reflex is set up and saliva will be secreted in response to switching on the light, without the intake of food. In this example light has become a conditioned food stimulus, a signal of the stimulation produced by the food.

According to Pavlov, the conditioned reflexes already present may serve as the basis for the formation of new conditioned reflexes. Such conditioned reflexes are called reflexes of the second order. Reflexes of even the third order may be formed on the basis of reflexes of the second order. Normally conditioned reflexes are produced not only in response to separate stimuli but also in response to complexes of stimuli acting on the organism simultaneously.

The principle of formation of conditioned reflexes is basically as follows. A conditioned stimulus causes a focus of excitation in the cerebral cortex. The next action of the unconditioned stimulus is accompanied by the appearance of a second focus of excitation (according to Pavlov, the centres of unconditioned reflexes have a "representation" in the cortex). A "temporary connection" arises between these two foci of excitation. After the conditioned and unconditioned stimuli have acted together several times, the temporary connection becomes stronger. As a result, the action of conditioned stimulus alone (without the subsequent action of the unconditioned stimulus) causes the appearance of two foci of excitation and a response reaction which corresponds to the unconditioned reflex. The reflex arc of a conditioned reflex will include the following parts: receptors which perceive the conditioned stimulus, a sensory nerve, an area in the cortex which perceives the conditioned stimulus, another area in the cortex which is connected with the centre of the unconditioned reflex, the centre of the unconditioned reflex, the motor nerve and the working organ.

The establishment of connections between the different foci of excitation in the cortex Pavlov termed **coupling**. Conditioned reflexes are formed as the result of coupling. The connections between the different areas of the cortex and the other parts of the central nervous system are apparently of a more complex character than appears from this schematic description.

**Inhibition in the cerebral cortex.** In the cerebral cortex, as in the other parts of the nervous system, there are processes of inhibition besides the process of excitation. Excitation and inhibition are basic nervous processes. External inhibition manifests itself in the weakening of conditioned reflexes or in their complete disappearance. There are two types of inhibition of conditioned reflexes, external and internal.

**External inhibition** of a conditioned reflex occurs as the result of the action of a new stimulus. In the cerebral cortex a new focus of excitation arises and causes depression (inhibition) of the existing focus of excitation. As a result, the previously formed reflex either weakens or completely disappears, i.e., is inhibited. For example, if an external stimulus (such as a noise or a shout) reaches the animal during the experiment on conditioned-reflex salivation, the secretion

of saliva ceases. The existing conditioned reflexes may also become inhibited when a new reflex is produced.

**Internal inhibition** arises in the same nerve cells of the cortex as those with which the given conditioned reflex is connected. One of the types of internal inhibition is extinction of a conditioned reflex. In order to preserve a conditioned reflex the action of the conditioned stimulus (for example, light) must from time to time be reinforced by the action of the unconditioned stimulus (food). If there is no such reinforcement for a long time, the conditioned reflex weakens and finally disappears, i.e., it becomes extinguished. The processes of formation and inhibition of conditioned reflexes operate throughout a man's life. Inhibition causes unnecessary temporary connections in the cortex to disappear.

**Radiation and concentration in the cerebral cortex.** The excitation arising in a definite area of the cerebral cortex spreads to the adjacent areas. This spread of excitation is called **radiation**. The opposite physiologic process in which the "diffuse" excitation concentrates in a definite area of the cerebral cortex is known as **concentration**. These two processes were first established by I. Pavlov in experiments on conditioned reflexes in dogs. For example, a salivary reflex may be formed in an animal in response to a certain sound. At first saliva is secreted not only in response to this sound, but also in response to other similar sounds. This reaction is due to the fact that the excitation radiates throughout the cerebral cortex. It is present not only in the nerve cells connected with the given conditioned stimulus, but also in the adjacent areas of the cortex which react to similar stimuli. If the conditioned stimulus is reinforced by an unconditioned stimulus (feeding), and the similar sounds closely resembling the former in tone are not reinforced, the excitation will soon become concentrated in the cortex. Saliva will be secreted only in response to the action of the reinforced conditioned stimulus. Reflex salivation to similar stimuli will be inhibited. Thus a differentiation (exact discrimination) of conditioned stimuli will occur. Inhibition is radiated and concentrated like excitation. The process of **induction** is connected with the concentration or inhibition. The concentration of excitation in a certain area of the cortex causes (induces) inhibition in the surrounding areas of the cortex; the concentration of inhibition is accompanied by appearance of excitation in the adjacent areas. The cortex may produce positive induction in the subcortical centres. For example, inhibition of the cortex (in alcoholic intoxication, or in anaesthesia) causes excitation in the subcortical centres, leading to motor restlessness.

**Analysing function of the cerebral cortex.** One of the functions of the cerebral cortex is to *analyse* the stimuli transmitted to it. The central nervous system possesses the ability to differentiate (discri-

minate) between the different stimuli, such as acoustic, optic, gustatory, pain, etc. Moreover, not only are the different stimuli differentiated (for example, the optic stimuli are distinguished from the acoustic), but the quality of the given type of stimulus is determined. For example, the visual analyser can detect the brightness of lighting, its colour and shades, the shape of objects and the distances between them. I. Pavlov wrote: "If the animal is continuously to orient and adapt itself to all conditions, the organism must evidently possess the ability to discriminate between the elements of the external world and, by breaking up the external world into elements, to analyse it". The analysis of the various stimuli is carried out through the sense organs (receptors) and the cerebral cortex. The primary (simplest) analysis takes place in the receptors. Each receptor perceives only certain stimuli (the retina of the eye reacts to optic stimuli, the organ of hearing reacts to noise, etc.). A more detailed and refined analysis of the stimuli takes place in the cerebral cortex. The whole of the cortex is a complex system of analysers in which the various stimuli are differentiated. At the same time the cortex connects and unifies various stimuli, i.e., it *synthetizes* them. The synthesis or coupling is effected through the appearance of connections (conditioned reflexes) and manifests itself in certain activity of the organism. Owing to the synthetizing ability of the cortex various stimuli are connected and perceived as a complex. The organism then reacts to the complex of stimuli. For example, if a conditioned salivary reflex is produced in the dog to a complex of optic, acoustic and tactile stimuli, none of these stimuli will evoke a reflex reaction on its own, and reflex salivation will occur only in response to the entire complex of stimuli. The cerebral cortex continuously analyses and synthetizes the stimuli it receives with the result that the organism responds to them with certain reactions.

#### CHARACTERISTICS OF MAN'S HIGHER NERVOUS ACTIVITY

The general patterns of higher nervous activity were at first established by working with animals in laboratories. In the main they are also inherent in man. Special investigations of higher nervous activity in children (N. Krasnogorsky, N. Kasatkin, et al.) have demonstrated that it is of a conditioned reflex character. As the child develops and associates with people, and is influenced by the surrounding social and biological environment, an increasing number of new "temporary connections" arise in its cerebral cortex and combine with the unconditioned reflexes. At the same time man's higher nervous activity differs from that of animals in some important respects. Man's brain is distinguished for its extraordinary complex structure and the connections between its various parts. The function of the



cerebral hemispheres, connected with the analysis and synthesis of various phenomena occurring in the external and internal environments, is extremely complex. "The cerebral hemispheres of man as a social being possess very highly refined synthetizing properties, which at once sharply distinguish his higher nervous activity from that of animals." (K. Bykov).

The main distinguishing characteristic of man's higher nervous activity is connected with human **speech**. The word, speech, underlies man's ability (the ability of his brain) to form general ideas and concepts and to think abstractly and logically. By thinking, using the brain and its cortex, man discovers the laws of nature, which enable him to remake it.

In virtue of the existence of the function of speech in man Pavlov established his theory of the *first and second signalling systems of man*. In animals the conditioned reflex activity is connected with the perception of direct stimuli from the external environment—light, heat, cold, odours, etc. These stimuli act on the receptors (sense organs) and are *signals* which evoke various reactions in the organism, i.e., various conditioned reflexes.

The activity of the cerebral cortex connected with the perception of direct stimuli (signals) from the external world Pavlov termed the *first signalling system of reality*. He wrote: "For an animal reality is signalled almost exclusively by stimuli and their traces in the cerebral hemispheres, acting directly on special cells of the visual, auditory and other receptors of the organism. This is the first signalling system of reality, common to man and animals". In addition to the first signalling system, man has a second signalling system of reality which is connected with the *function of speech*, the word heard and seen. The stimuli which evoke conditioned reflexes in man are not only the actual objects and phenomena of the external world, i.e., the direct *signals of reality*, but also the words designating these objects and phenomena. Consequently, words are *signals of the signals* of the first system. For example, in man conditioned-reflex secretion of saliva may take place not only in response to the sight and odour of a lemon, but also in response to the word "lemon". According to Pavlov's definition, "for man the word is as much of a real conditioned stimulus as any other stimulus. It is the signal of the first signals and constitutes the second, exclusively human, signalling system of reality".

When a child learns to speak, the utterance and hearing of a certain word (for example, "lemon") are combined with various stimuli arising when the child makes the acquaintance of this object (in this example with optic, gustatory and olfactory stimuli). The stimuli arising in the cortex upon the utterance of the word become, according to the principle of the setting up of conditioned reflexes, connected

by a temporary bond with the stimuli of the first signalling system. The word thus becomes a signal of the designated object.

The cortex synthesizes the signals of various words so that they are perceived not in isolation but in combination, i.e., the words form very simple and then increasingly more complex sentences. By operating with words man acquires the ability to perceive and transmit numerous signals quickly and economically, which makes possible extensive human intercourse in the process of man's labour activity. According to Pavlov's definition, the verbal signals "...are an abstraction from reality and allow of generalization, which constitutes our additional, exclusively human, higher thinking which creates at first general human empiricism and finally science—the instrument of man's higher orientation in the surrounding world and in himself". "The word", wrote Pavlov, "made us human".

The significance of the verbal stimulus also manifests itself in pathologic processes. For example, verbal suggestion exerts a considerable influence on the patient's mind and the course of disease. A word carelessly uttered in the presence of a patient may change his condition for the worse. An optimistic suggestion making the patient confident in his recovery may also affect the result of the disease.

Pavlov's theory of man's second signalling system serves as the basis for understanding the physiologic essence of thinking, man's mental activity. Before the time of Sechenov and Pavlov, it was thought that man's psychic activity, or as it was called, "psychic life", had nothing to do with bodily activity, i.e., with the processes operating in the human body. Some scientists still hold that it is impossible to study man's mental activity.

Having established the basic patterns of higher nervous activity Pavlov demonstrated that man's mental life is based on the physiological processes operating in the brain.

## SLEEP

Sleep is a normal physiologic function of the organism of animals and man. A human adult sleeps 7-8 hours a day, a newborn child sleeps about 20 hours, and an eight-year-old child sleeps 10-11 hours a day. The physiologic nature of sleep was studied by Pavlov who regarded sleep as *inhibition of cortical activity*, spreading to certain subcortical parts.

A prolonged state of excitation in the nerve cells of the cerebral cortex tires and exhausts them and may injure them. According to Pavlov's theory, inhibition in the cerebral cortex, which causes sleep, plays a protective role (*protective inhibition*): during sleep the nerve cells "rest" and their excitability is restored.

The depth of sleep depends on the strength of the inhibitory process in the cerebral cortex. Sometimes separate foci of excitation or, in Pavlov's expression, "sentry posts of excitation" may persist in the cortex during sleep. For example, a mother of a little child may not respond to loud sounds, but wakes up at the slightest rustle caused by the movements of the child.

Various changes are observed in the organism during sleep: for

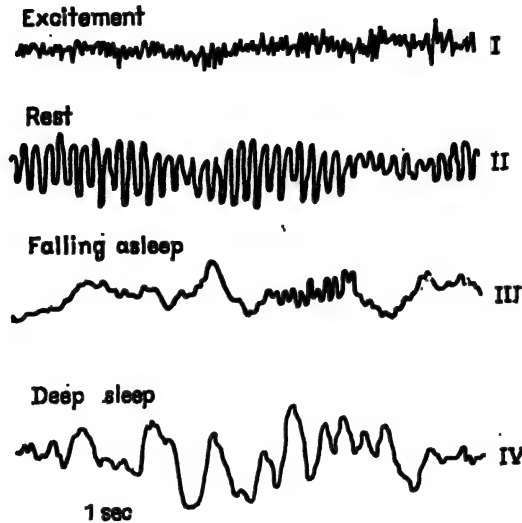


Fig. 138. Human electroencephalogram

*I*—excitation; *II*—complete rest; *III*—falling asleep; *IV*—deep sleep

example, respiration becomes deeper, the heart rate becomes slower, metabolism decreases, etc.

The reticular formation of the brain stem plays an important part in the mechanism of development of sleep inhibition. Inhibition develops and sleep sets in when its activating influence on the cortex ceases. When the reticular formation is excited sleep is replaced by wakefulness.

### ELECTROENCEPHALOGRAPHY

The brain possesses electric activity. The electric activity of the brain may be recorded by means of a special instrument called an **electroencephalograph**. In electroencephalography electrodes are ap-

plied to the skin of various parts of the head or, in surgical operations, directly to the brain. The resultant complex curve is called an electroencephalogram. A human electroencephalogram shows various rhythms. The character of the rhythms varies with the functional state of the brain of healthy man (rest, active state, sleep, etc.) and with certain diseases (brain tumours, cerebral haemorrhages, epilepsy, etc.).

Several rhythms are distinguished (Fig. 138). For example, alpha rhythm (smooth, regular oscillations) is well pronounced when the subject is at rest, lying with his eyes closed; this rhythm prevails in the occipital region of the cerebral hemispheres. During mental work an electroencephalogram shows a beta rhythm (low potential, fast waves); this rhythm prevails in the frontal region. In some cerebral tumours delta rhythm is observed.

Electroencephalography is not only a method of determining the functional state of the nerve cells; in some cases it helps to establish the character of the disease and to localize the pathological process in the brain.

### MENINGES OF THE BRAIN AND SPINAL CORD

The brain and spinal cord have three membranes\*: the outer is called the dura, the middle is called the arachnoid, and the inner is called the pia (Fig. 139). The membranes of the brain are continuous with those of the spinal cord.

The **dura** (*dura mater*) is a fibrous membrane. In the cranial cavity it closely adheres to the bones and carries out the function of the periosteum; in the vertebral canal, between the dura and vertebrae, there is a well-pronounced space filled with adipose tissue and blood vessels, especially veins\* (**epidural space**). The dura of the brain has processes which are located in the fissures between the various parts of the brain. They include the falx cerebri (between the two hemispheres), and the tentorium (which separates the occipital lobes of the hemispheres from the cerebellum). The dura of the brain contains venous sinuses which form a reservoir for the venous blood draining from the veins of the brain. The blood then flows from the venous sinuses to the internal jugular vein. The dura of the spinal cord covers not only the spinal cord but also the cauda equina.

The **arachnoid** (*arachnoidea*) is a thin membrane located under the dura.

The **pia** (*pia mater*) closely adheres to the brain and the spinal cord. It has a large number of blood vessels and is therefore also called the **vascular membrane**. The pia of the brain is not only located on the

\* The membranes of the brain and spinal cord are also called *meninges* (singular—*meninx*); inflammation of the meninges is called *meningitis*.

surface, but also penetrates into the fissures and ventricles of the brain where it forms the so-called **vascular plexuses**. Such plexuses are found in each ventricle.

The meninges of the brain and spinal cord play a protective role. The vessels of the pia participate in supplying blood to the brain. Between the meninges there are slit-like cavities, called the **menin-**

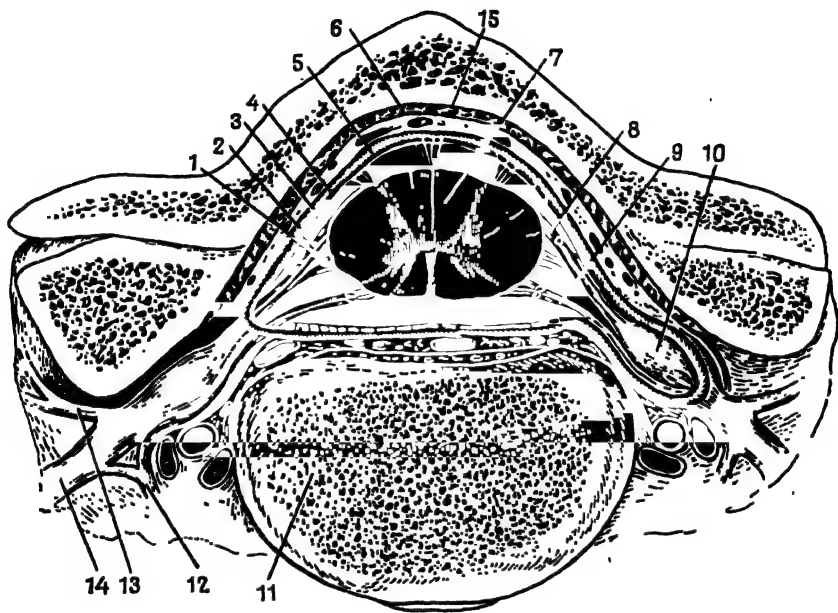


Fig. 139. Meninges of the spinal cord

1—pia mater; 2—subarachnoid space; 3—arachnoid; 4—subdural space; 5—dura mater; 6—epidural space; 7—spinal cord; 8—posterior root of spinal nerve; 9—anterior root; 10—ganglion; 11—vertebra; 12—branch of spinal nerve to sympathetic trunk; 13—posterior branch of spinal nerve; 14—anterior branch; 15—periosteum of vertebra

**geal spaces.** The space between the pia and the arachnoid is called the **subarachnoid space**. This space contains cerebrospinal fluid. The space between the arachnoid and the dura is called the **subdural space**.

The meninges of the spinal cord descend to the level of the sacral vertebrae, and thus the vertebral canal has meningeal spaces not only along the spinal cord but also below it.

### CEREBROSPINAL FLUID

The cerebrospinal fluid (liquor cerebrospinalis) fills the subarachnoid space, the ventricles of the brain and the canal of the spinal cord. The body of an adult has a total of about 150 ml of this fluid. This fluid is colourless and transparent, and contains small amounts of proteins, glucose and various salts (potassium, calcium, etc.). It creates a definite pressure inside the skull and, together with the meninges of the brain, performs a protective function; it also participates in metabolism in the brain and the spinal cord.

Cerebrospinal fluid is continuously formed in the vascular plexus of the cerebral ventricles. At the same time it flows out of the subarachnoid space into the veins and the lymphatics.

In some diseases (for example, in meningitis) the composition and colour of the cerebrospinal fluid change. At the same time the intracranial pressure may rise because of increased production of fluid. In such cases a spinal puncture is made. The needle is introduced into the subarachnoid space of the spinal cord between the third and fourth or the fourth and fifth lumbar vertebrae and fluid is withdrawn and examined.

### SPINAL NERVES

There are 31 pairs of spinal nerves: eight pairs of cervical, twelve pairs of thoracic, five pairs of lumbar, five pairs of sacral and one pair of coccygeal nerves. All have various functions. Each nerve is formed by the junction of two roots: the anterior or motor root, and the posterior or sensory root. The roots join in the intervertebral foramen. When a spinal nerve leaves the intervertebral foramen it divides into anterior and posterior branches (Fig. 140); both branches have various functions.

The posterior branches of spinal nerves innervate the muscles of the back, and the skin in the region of the spine.

The anterior branches of spinal nerves interlace and form nervous plexuses. Four such plexuses are distinguished on each side: cervical, brachial, lumbar and sacral. Each plexus gives off several nerve branches which extend to definite muscles and parts of the skin.

The anterior branches of the thoracic nerves do not form plexuses.

The cervical plexus (plexus cervicalis) is formed by the anterior branches of the four superior cervical nerves and is located in the region of the neck under the sternocleidomastoid muscle. This plexus gives off the following branches (Fig. 141).

1. *Cutaneous nerves of the neck*, innervating the skin of the neck.
2. *Great auricular nerve*, innervating the skin near the pinna of the ear.
3. *Lesser occipital nerve*, innervating the skin of the occipital region.

4. *Supraclavicular* nerves, innervating the skin of the supraclavicular and subclavian regions.

5. *Phrenic nerve* descends from the region of the neck into the thoracic cavity where it innervates the diaphragm and partly innervates the pleura and pericardium. The cervical plexus also gives off branches to the deep muscles of the neck.

The *brachial plexus* (plexus brachialis) is formed by the anterior branches of the four inferior cervical nerves and part of the anterior

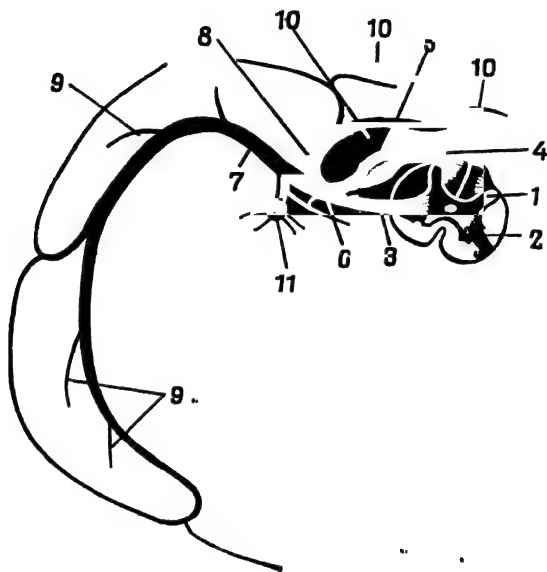


Fig. 140. Diagram showing formation and branching of a spinal nerve  
 1—dorsal horn of spinal cord; 2—ventral horn of spinal cord; 3—anterior root of spinal nerve; 4—posterior root of spinal nerve; 5—spinal ganglion; 6—spinal nerve; 7—anterior branch of spinal nerve; 8—posterior branch of spinal nerve; 9—anterior branch giving off branches to muscles and skin; 10—posterior branch giving off branches to muscles and skin; 11—sympathetic ganglion

branch of the first thoracic nerve. In the neck this plexus traverses the interscalenial space and then passes into the axilla.

In the region of the neck (above the clavicle) the brachial plexus gives off so-called short branches which innervate the pectoralis major and minor, anterior serratus, latissimus dorsi, subscapularis, supraspinatus, infraspinatus, rhomboideus and levator scapuli muscles.

In other words the short branches of the brachial plexus innervate the muscles which move the shoulder girdle.



**Fig. 141. Nerves of the head and neck**

**1—cutaneous colli; 2—supraclavicular nerves; 3—great auricular nerve; 4—lesser occipital nerve; 5—accessory nerve (eleventh pair of cranial nerves); 6—posterior branch of second cervical (spinal) nerve; 7, 9, 10 and 11—branches of trigeminal nerve (fifth pair of cranial nerves); 8—facial nerve (seventh pair of cranial nerves); branches of the facial nerve to muscles of facial expression are shown**



In the axilla (below the clavicle) the brachial plexus gives off long branches which innervate the upper extremity (Fig. 142). These include:

1. The *medial cutaneous nerve of the arm* which innervates the skin of the medial part of the arm.
2. The *medial cutaneous nerve of the forearm* which innervates the skin of the anteromedial part of the forearm.



Fig. 142. Branches of the brachial plexus

1—axillary vein; 2—axillary artery; 3—brachial plexus; 4—short branches of brachial plexus to pectoralis major and minor muscles; 5—musculocutaneous nerve; 6—median nerve; 7—medial cutaneous nerve of forearm; 8—ulnar nerve; 9—radial nerve; 10—axillary nerve; 11—medial cutaneous nerve of arm; 12—second rib; 13—serratus anterior muscle; 14—short branch of brachial plexus to latissimus dorsi muscle; 15—short branch of brachial plexus to serratus anterior muscle; 16—short branch to subscapularis muscle

3. The *musculocutaneous nerve of the upper extremity* which innervates the anterior muscles of the upper arm and the skin of the anterolateral part of the forearm.

4. The *median nerve* which does not give off any branches on the upper arm; in the forearm it innervates all the anterior muscles except the flexor carpi ulnaris and part of the flexor digitorum profundus. The median nerve extends from the forearm to the palmar aspect of the hand, where it innervates the thenar muscles, two lumbricals and the skin of three-and-a-half fingers, beginning with the thumb.

5. The *radial nerve* which innervates the triceps brachii and the skin of the posterior surface of the upper arm, the posterior muscles

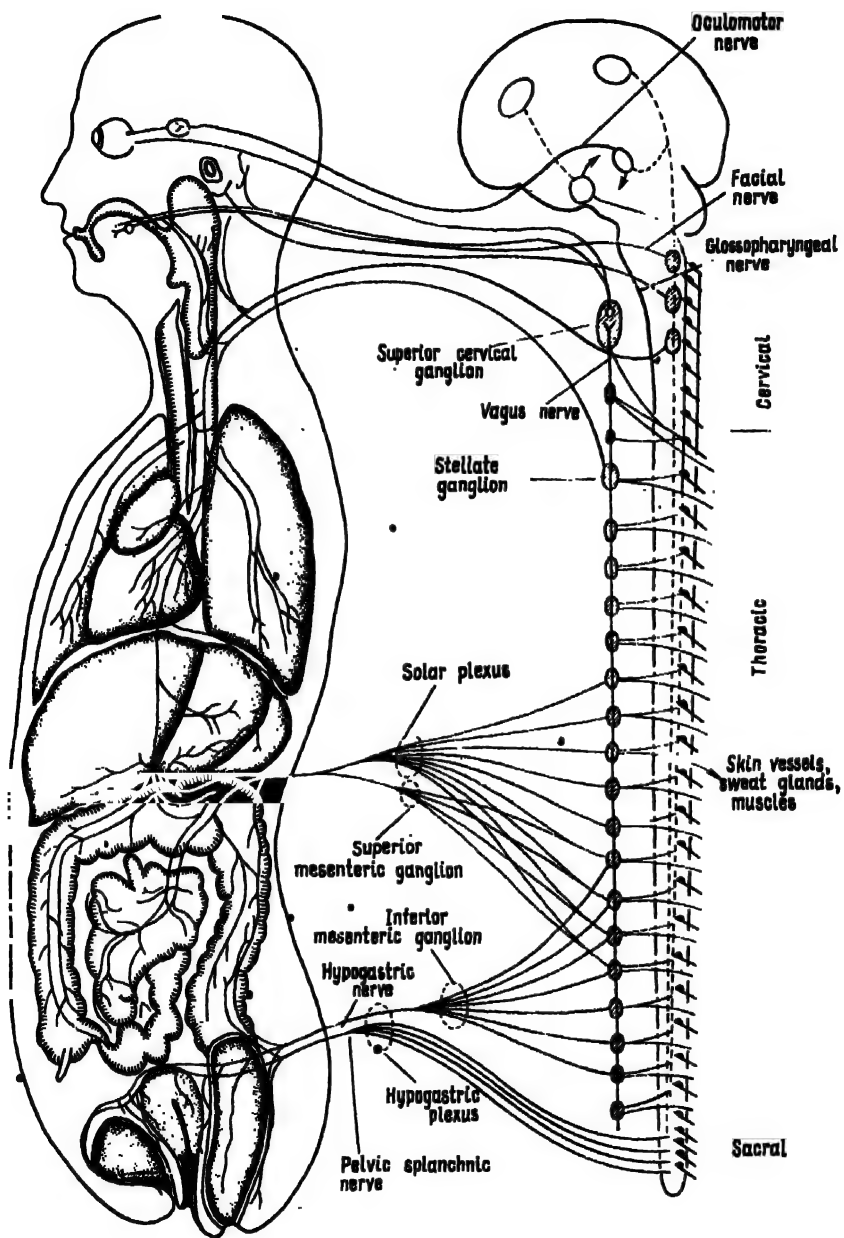


Plate VIII. Vegetative part of the nervous system (diagram). Sympathetic nuclei (centres), ganglia and fibres shown in red, parasympathetic — in blue



and skin of the posterior surface of the forearm, and the skin of the dorsal surface of two-and-a-half fingers, beginning with the thumb.

6. The *ulnar nerve* which gives off no branches in the upper arm; in the forearm it innervates the flexor carpi ulnaris and part of the flexor digitorum profundus. In the lower part of the forearm the nerve divides into two branches which extend to the hand where one branch innervates the skin of the dorsal surface of two-and-a-half fingers, beginning with the little finger. The other branch innervates the muscles of the hypothenar eminence, all the interossei, the medial two lumbricals of the hand, and the palmar surface of one-and-a-half fingers, beginning with the little finger. It should be remembered that the ulnar nerve passes from the upper arm to the forearm in the superficial groove between the medial epicondyle of the humerus and the olecranon process of the ulna; it may be easily injured.

The *axillary nerve* is a comparatively short branch which innervates the deltoid muscle, the skin over this muscle and the shoulder joint capsule.

The anterior branches of the thoracic nerves, as mentioned above, do not form a plexus. They are called *intercostal nerves*; they pass between the ribs and innervate the intercostal muscles, the skin of the chest and the pleura. The inferior intercostal nerves also participate in innervating the muscles and skin of the anterior abdominal wall.

The *lumbar plexus* (plexus lumbalis) is formed by the anterior branches of the three superior lumbar nerves and part of the anterior branch of the twelfth thoracic



Fig. 143. Nerves of the thigh (anterior view); branches of the lumbar plexus

1—femoral nerve; 2—branch of femoral nerve to skin of anterior surface of thigh; 3—branches of femoral nerve to muscles; 4—saphenous nerve; 5—obturator nerve; 6—great saphenous vein

and fourth lumbar nerves and is located behind the psoas muscle.

The branches of this plexus innervate the skin and muscles of the lower part of the abdominal wall, the psoas and iliacus muscles, the anterior and medial group of the thigh muscles and the skin above them, and the skin of the medial surface of the shank.



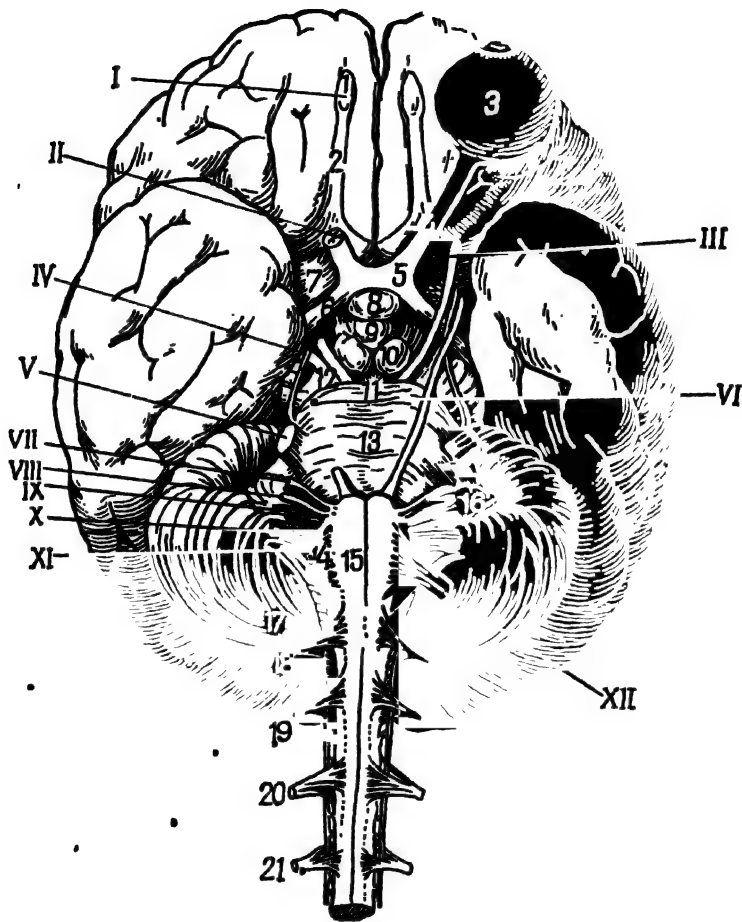
Fig. 144. Branches of the sacral plexus

1—sciatic nerve; 2—posterior cutaneous nerve of thigh; 3—branches to skin of gluteal region; 4—inferior gluteal nerve; 5—superior gluteal nerve

The largest branches of the lumbar plexus are as follows (Fig. 143).

1. The *femoral nerve*, located under the inguinal ligament, extends to the anterior surface of the thigh where it innervates the quadriceps femoris and the sartorius muscles and the skin above them. It also gives off a branch, the *saphenous nerve*, which innervates the skin of the medial surface of the shank.

The *obturator nerve* extends to the thigh through the obturator canal. On the thigh it innervates the medial (adductor) muscles and the skin above them.



**Fig. 145. Base (inferior surface) of the brain**

*I, II, III, IV, V, VI, VII, VIII, IX, X, XI and XII—corresponding cranial nerves; 1—olfactory bulb; 2—olfactory tract; 3—eyeball; 4—optic nerve; 5—optic chiasm; 6—optic tract; 7—olfactory trigone; 8—hypophysis; 9—tuber cinereum; 11—mammillary body; 11—interpeduncular fossa; 12—cerebral peduncle; 13—pons varolii; 14—olive; 15—pyramid; 16—cerebellar peduncle; 17—cerebellum; 18, 19, 20 and 21—superior spinal nerves*

The **sacral plexus** (plexus sacralis) is formed by the anterior branches of the fourth (part) and fifth lumbar nerves, and all the sacral and coccygeal nerves. It is located in the cavity of the true pelvis on the piriformis muscle.

The branches of this plexus innervate all the muscles of the pelvis except the iliopsoas muscle, the skin of the perineum, the posterior muscles of the thigh and the skin of the shank and foot, except for the skin on the medial surface of the shank.

The largest branch of the sacral plexus (and generally the largest nerve in the human body) is the *sciatic nerve*. This nerve emerges from the cavity of the true pelvis and extends to the posterior surface of the thigh (Fig. 144), where it innervates the semitendinosus, semimembranosus and biceps femoris muscles. Usually the sciatic nerve divides into two branches in the upper corner of the popliteal fossa. These branches are the *tibial nerve* and the *common peroneal nerve*.

The branches of the tibial nerve innervate the posterior muscles of the shank and the skin above them, and the muscles and skin of the plantar part of the foot.

The common peroneal nerve in its turn divides into the *deep* and *superficial peroneal nerves*. The former innervates the anterior muscles of the shank and the muscles of the dorsum of the foot, and the latter innervates the lateral muscles of the shank and the skin of the dorsum of the foot.

### CRANIAL NERVES

There are 12 pairs of cranial nerves (Fig. 145). Each pair has an ordinal number (first, second, etc., up to the twelfth) and a proper name. Some cranial nerves are sensory nerves (the first, second and eighth pairs), others are motor nerves (the third, fourth, sixth, seventh, eleventh and twelfth) and still others are mixed nerves (the fifth, ninth and tenth).

The first pair, the **olfactory nerves** (n. olfactorius), are sensory nerves and are formed by the processes of special sensory (olfactory) cells which are located in the mucous membrane of the upper part of the nasal cavity and constitute the organ of smell. The processes unite in thin bundles, called *olfactory filaments*. From the nasal cavity the olfactory filaments pass through the perforated plate of the ethmoid bone into the cranial cavity. Here they enter the so-called *olfactory bulb* which passes into the olfactory tract.

Along the olfactory nerve impulses are transmitted from the cells of the organ of smell to the cerebral cortex.

The second pair, the **optic nerves** (n. opticus) are sensory nerves; they are formed by the processes of the nerve cells located in the retina of the eye (Fig. 145). From the orbit each optic nerve passes

through the optic foramen into the cranial cavity. In the cranial cavity the fibres of the two optic nerves—right and left—partly decussate. After the decussation the nerve fibres extend along the optic tract to the pulvinar of the thalamus, the lateral geniculate body and the superior colliculus of the corpora quadrigemina which contains the subcortical visual centres. The subcortical visual centres in their turn communicate with the cortex. The entire pathway from the retina of the eye to the cerebral cortex is called the *optic tract*.

The third pair, the *oculomotor nerves* (n. oculomotorius), are motor nerves; they are formed by the processes of the cells of their nuclei in the cerebral peduncles (midbrain). From the cranial cavity each of these nerves passes through the superior orbital fissure into the orbit where it innervates several muscles of the eyeballs (the rectus oculi superior, inferior and medial, and the obliquus oculi inferior) and the levator palpebrae superioris muscle.

The fourth pair, the *trochlear nerves* (n. trochlearis), are motor nerves; they are formed by the processes of the cells of their nuclei in the cerebral peduncles (Fig. 145). From the cranial cavity each of these nerves passes through the superior orbital fissure into the orbit where it innervates the obliquus oculi superior muscle.

The fifth pair, the *trigeminal nerves* (n. trigeminus), are mixed, consisting of motor and sensory fibres (Fig. 146).

The *motor fibres* are processes of the nuclei of these nerves located in the pons varolii.

The *sensory fibres* are processes of the cells of the *semilunar (gasserian) ganglia* of these nerves. These ganglia are located on the anterior surface of the petrous pyramids near their apices.

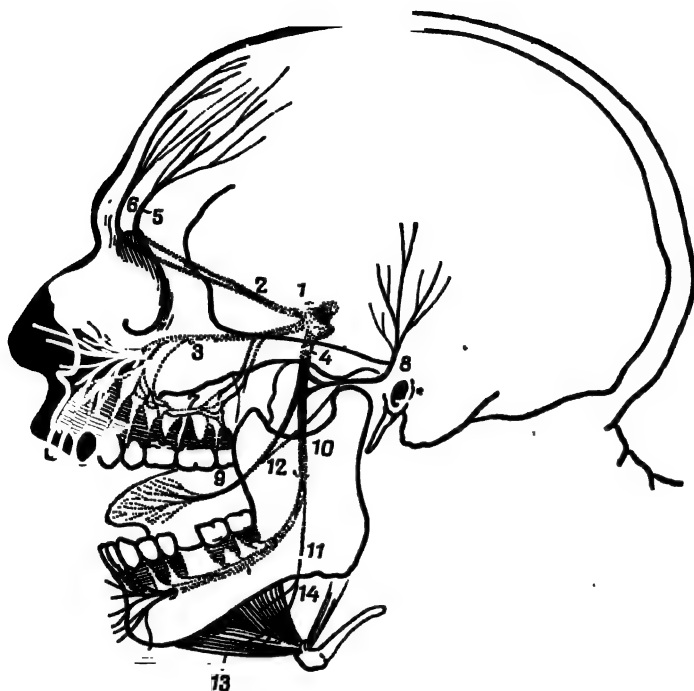
The trigeminal nerve has three branches.

The first branch, the *ophthalmic nerve*, is a sensory nerve. It enters the orbit from the cranial cavity through the superior orbital fissure and divides into small branches. It innervates the skin of the forehead, the upper eyelid, the conjunctiva of the eyelids and the eyeball.

The second branch, the *maxillary nerve*, is also a sensory nerve. It enters the pterygopalatine fossa from the cranial cavity through the foramen rotundum and divides into several branches. These branches innervate the upper teeth; the skin of the upper lip, the lower eyelid and nose, the mucous membrane of the upper lip, the hard and soft palates, the nasal cavity and the cavity of the maxillary sinus. The largest branch of the maxillary nerve is the inferior orbital nerve which passes through the inferior orbital canal and the orifice in the maxilla.

The third branch of the trigeminal nerve, the *mandibular nerve*, is functionally a mixed nerve. It emerges from the cranial cavity through the foramen ovale and passes into the infratemporal fossa where





**Fig. 146. Trigeminal nerve (diagram)**

**1—semilunar (gasserian) ganglion of trigeminal nerve; 2—first branch of trigeminal nerve; 3—second branch of trigeminal nerve; 4—third branch of trigeminal nerve; 5 and 6—branches of first branch of trigeminal nerve to skin of forehead; 7—branches of second branch of trigeminal nerve to upper teeth; 8—branch of third branch of trigeminal nerve to skin of temporal region; 9—lingual nerve; 10—inferior alveolar nerve; 11—branch to mylohyoid muscle; 12—chorda tympani; 13—biventer muscle; 14—mylohyoid muscle**

it divides into branches. These branches innervate the lower teeth, the skin of the lower lip, chin and temporal region, the mucous membrane of the lower lip, the floor of the oral cavity, the tip and body of the tongue, all the masticatory muscles, the muscle which tenses the soft palate (tensor veli palatini), the mylohyoid muscle and the anterior belly of the biverter muscle. The largest branches of the mandibular nerve are the *lingual nerve* (which extends to the tongue) and the *inferior alveolar nerve* (which traverses the mandibular canal). The lingual nerve is joined by a branch of the *facial nerve* (seventh pair) called the *chorda tympani*. This branch contains gustatory fibres for the papillae of the tongue and secretory fibres for the submaxillary and sublingual salivary glands.

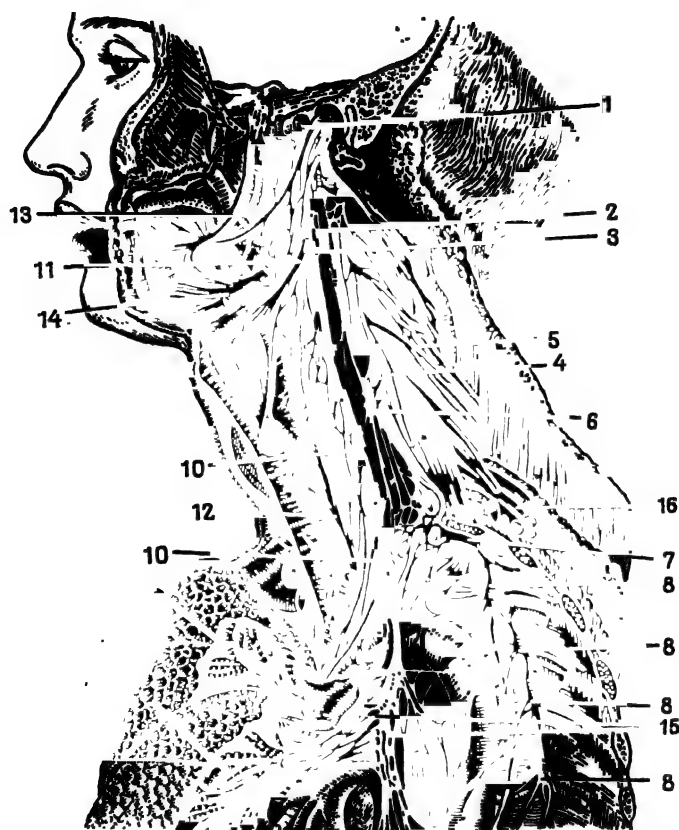
The sixth pair, the *abducens nerves* (n. abducens), are motor nerves; they emerge from the cranial cavity through the superior orbital fissures and extend to the orbits where they innervate the lateral rectus oculi muscles. The nuclei of these nerves are located in the pons varolii.

The seventh pair, the *facial nerves* (n. facialis), are motor nerves; they are formed by the processes of the cells of their nuclei in the pons varolii (see Fig. 145). Each of these nerves traverses an internal auditory canal and then passes through the facial canal of the temporal bone. The facial nerves are joined by so-called *intermedius nerves* (which emerge from the brain but have no ordinal number). The intermedius nerves contain gustatory fibres for the tongue (for the papillae) and secretory fibres for all the glands of the head (salivary, lacrimal and mucous glands) except the parotid glands. Thus, the facial nerves are composed not only of motor fibres, but also of gustatory and secretory fibres. In the canal of the temporal bone the facial nerves give off several branches, the largest of them being the *chorda tympani*, mentioned above.

The nerve emerges from the canal of the temporal bone through the stylomastoid foramen, and in the parotid gland it divides into numerous branches which innervate all the muscles of facial expression and certain muscles of the neck (the platysma muscle, etc.).

The eighth pair, the *acoustic nerves* (n. statoacousticus), are sensory nerves; each of these nerves is formed by the cell processes of its two ganglia located in the temporal bone. Each nerve innervates the internal ear and consists of two bundles, the *vestibular nerve* and the *cochlear nerve*, which transmit impulses from the corresponding parts of the internal ear to the brain. Each nerve traverses the internal auditory canals.

The ninth pair, the *glossopharyngeal nerves* (n. glossopharyngeus), are mixed nerves containing motor, sensory and secretory (parasympathetic) fibres; each nerve emerges from the cranial cavity through the jugular foramen (Fig. 147). Each nerve has nuclei in the medulla



**Fig. 147. Glossopharyngeal and vagus nerves**

1—glossopharyngeal nerve; 2—superior cervical ganglion of sympathetic trunk; 3—vagu. nerve; 4—phrenic nerve; 5—branches of cervical plexus; 6—middle and 7—inferior cervical ganglia of sympathetic trunk; 8—thoracic ganglia of sympathetic trunk; 9—branches of vagus nerve to heart; 11 and 12—branches of vagus nerve to larynx (inferior and superior laryngeal nerves); 13—lingual nerve; 14—hypoglossal nerve; 15—branches of vagus nerve to lungs; 16—brachial plexus

oblongata and ganglia in the region of the jugular foramen. The motor fibres of the glossopharyngeal nerves participate in innervating the muscles of the pharynx; the secretory fibres innervate the parotid glands, and the sensory fibres innervate the mucous membrane of the pharynx and the base of the tongue. The sensory fibres contain gustatory fibres for the papillae of the tongue.

The tenth pair, the **vagus nerves** (n. vagus), are mixed nerves containing motor, sensory and parasympathetic fibres (see Fig. 147). These nerves were given their name because they give off branches to many organs in various regions. They have nuclei in the medulla oblongata and ganglia in the region of the jugular foramina. The nerves emerge from the cranial cavity through these foramina and pass to the neck, the thoracic cavity and the abdominal cavity. In the region of the neck they are located beside the common carotid arteries and the internal jugular veins; in the thoracic cavity both nerves (right and left) lie on the walls of the oesophagus.

Each vagus nerve gives off numerous branches which innervate all the muscles of the soft palate (except the tensor muscle), the constrictor muscles of the pharynx, larynx, thyroid gland, oesophagus, trachea, bronchi, lungs, heart, stomach, liver, pancreas, spleen, all of the small intestine and the greater part of the large intestine (caecum, ascending and transverse colon). Thus, the vagus nerves help to innervate the internal organs in the region of the neck, and the organs of the thoracic cavity and the abdominal cavity, except for part of the large intestine (they do not innervate the organs of the true pelvis).

The fibres of the vagus nerves extending to glands (secretory fibres) and to internal organs with smooth muscle tissue are called *parasympathetic*.

The eleventh pair, the **accessory nerves** (n. accessorius), are motor nerves; each of these nerves has nuclei in the medulla oblongata and the upper part of the spinal cord. The nerves emerge from the cranial cavity through the jugular foramina and innervate the sternocleidomastoid and trapezius muscles (see Fig. 141).

The twelfth pair, the **hypoglossal nerves** (n. hypoglossus), are motor nerves; each nerve consists of fibres which are cell processes of the nuclei located in the medulla oblongata (see Fig. 147). Each nerve emerges from the cranial cavity through the canal in the occipital bone and innervates all the muscles of the tongue. It also gives off a so-called descending branch to the muscles of the neck lying below the hyoid bone.

### VEGETATIVE NERVOUS SYSTEM

In studying the nervous system it is customary to treat separately the part which innervates the internal organs, glands and blood vessels. This part is called the **vegetative part of the nervous system** or the **vegetative nervous system**.

The vegetative nervous system, like the entire nervous system, consists of nerve cells and their processes, the nerve fibres.

Vegetative nerve cells form accumulations, called **vegetative nuclei**, in the brain and spinal cord. Moreover, the vegetative nervous system has a large number of nerve ganglia located near the vertebral column, near the internal organs or in their walls.

The nerve fibres of the vegetative nervous system emerge from the brain or the spinal cord—they are called **preganglionic**—as part of certain cranial and spinal nerves and extend to the cells of the vegetative ganglia. The ganglia in their turn give off nerve fibres—**postganglionic**—which innervate the internal organs. The fibres of the vegetative nervous system form plexuses, called *vegetative nervous plexuses*, near the internal organs or in their walls. These plexuses contain nerve cells.

The vegetative nuclei located in the brain and spinal cord constitute the **central part of the vegetative system**, and the nerve ganglia and fibres constitute its **peripheral part**.

The vegetative nervous system consists of two divisions—sympathetic and parasympathetic.

**Sympathetic division.** The sympathetic division of the vegetative nervous system consists of the lateral horns of the spinal cord, the sympathetic trunk, and the sympathetic nervous plexuses (Plate VIII).

Lateral horns of the spinal cord are present in its thoracic and lumbar divisions. They contain sympathetic nerve cells and constitute the central part of the sympathetic division of the vegetative system. The cell processes of the lateral horns emerge from the spinal cord as part of the corresponding spinal nerves, separate from these nerves, and extend to the sympathetic trunk.

The **sympathetic trunk** is paired (right and left) and is located on both sides of the vertebral column. It consists of nerve ganglia and the branches connecting them. Cervical, thoracic, lumbar and pelvic parts of the sympathetic trunk are distinguished. Each part has a certain number of ganglia which give off nerve branches which form part of the vegetative nervous plexuses.

The **cervical part** of the sympathetic trunk consists of three nerve ganglia which give off branches to the heart and the carotid arteries. These branches form plexuses around the arteries. The fibres of these plexuses innervate the blood vessels and those internal organs of the neck and head to which branches of the carotid arteries extend (i.e., pharynx, salivary glands, lacrimal glands, muscle which dilates the pupil, etc.).

The **thoracic part** has 10-11 ganglia. These ganglia give off the greater and lesser *splanchnic nerves* (*nn. splanchnici*) which pass through the diaphragm into the abdominal cavity and participate in the formation of the solar plexus. The ganglia of the thoracic part of the

sympathetic trunk also give off branches to the thoracic aorta, oesophagus, bronchi and lungs. The nerve ganglia of the lumbar and pelvic parts of the sympathetic trunk give off branches which participate in the formation of vegetative nervous plexuses in the abdominal and pelvic cavities. The largest of them is called the solar plexus.

The *solar plexus* is located in the abdominal cavity on the aorta, around the coeliac artery. It is formed by the splanchnic nerves, branches of the ganglia of the lumbar part of the sympathetic trunk, and branches of the vagus nerve. This plexus has large nerve ganglia. It gives off vegetative nerve fibres which form secondary nervous plexuses along the walls of arteries and extend to all organs of the abdominal cavity. These plexuses include the hepatic, splenic, superior mesenteric, inferior mesenteric, etc.

The cavity of the true pelvis contains a paired *coeliac plexus* (near the internal iliac artery). The branches of this plexus innervate the organs of the true pelvis.

**Parasympathetic division.** The parasympathetic division of the vegetative nervous system consists of the parasympathetic nuclei, ganglia and fibres.

The parasympathetic nuclei are located in the brain stem and in the sacral division of the spinal cord (see Plate VIII). They constitute the central part of the parasympathetic division of the vegetative system. The parasympathetic nuclei located in the brain stem give off nerve fibres which form part of the third, seventh, ninth and tenth pairs of the cranial nerves. The parasympathetic fibres of the oculomotor nerve (third pair) innervate in the eyeball the sphincter pupillae muscle which constricts the pupil, and the ciliary muscle. The parasympathetic fibres of the *intermedius nerve* join the facial nerve (seventh pair) in the canal of the temporal bone. These fibres innervate the submaxillary and sublingual glands, the mucous glands of the nasal and oral cavities, and the lacrimal glands. The parasympathetic fibres of the glossopharyngeal nerve innervate the parotid glands (the parasympathetic fibres to the glands are also called *secretory*). The vagus nerve (tenth pair) contains parasympathetic fibres which extend to the internal organs of the neck, thoracic and abdominal cavities (thyroid gland, parathyroid and thymus glands, heart, lungs, oesophagus, stomach, small intestine, greater part of the large intestine, liver, pancreas, spleen, kidneys, suprarenal and sex glands).

The parasympathetic fibres emerge from the sacral division of the spinal cord as part of the sacral spinal nerves and innervate the internal organs of the true pelvis (urinary bladder, uterus, rectum, etc.).

The parasympathetic division of the vegetative nervous system has a large number of nerve ganglia which are located near the organs and in their walls (forming part of the vegetative plexuses). The para-

sympathetic fibres emerging from the brain and spinal cord extend to these ganglia, which give off nerve fibres to internal organs.

When considering the vegetative nervous system it is necessary to note that the hypothalamic region of the interbrain contains the so-called higher vegetative centres, which exert a regulatory influence on metabolism, heat production and other processes operating in the internal organs. The functions of these organs are under the control of the cerebral cortex.

**Role of the vegetative nervous system.** The vegetative nervous system regulates all the processes in the internal organs: glandular secretion, contraction of smooth muscles, constriction of blood vessels, cardiac activity, metabolism, etc.

All internal organs receive sympathetic and parasympathetic innervation. The two divisions of the vegetative nervous system produce unequal and usually contrary effects on the internal organs. For example, nerve impulses transmitted along sympathetic fibres dilate the pupils, decrease the secretion of the salivary and lacrimal glands, and constrict the small arteries and veins, but dilate the coronary arteries of the heart, elevate blood pressure, increase the heart rate, slow down intestinal peristalsis, decrease secretion of the gastric glands, relax bronchial muscles, reduce heat loss, etc. Stimulation of the parasympathetic division of the vegetative nervous system causes opposite phenomena, i.e., it constricts the pupils, encourages secretion of the salivary and lacrimal glands, slows down the heart rate, increases intestinal peristalsis, excites secretion of the gastric glands, contracts bronchial muscles, dilates blood vessels, increases heat loss, etc.

The fact that the sympathetic and parasympathetic divisions of the vegetative nervous system perform different functions does not imply "antagonism" between them. In the living organism the effects of the two divisions on the different organs are co-ordinated to form a single system. The regulation of the work of the organs depends on the interaction of the opposing effects of the sympathetic and parasympathetic divisions of the vegetative system. The work of the heart, the glands of the digestive tract, metabolism and other processes in the organism cannot proceed normally without the regulatory effects of both the sympathetic and parasympathetic divisions.

The research carried out by Pavlov and his pupils has shown that the vegetative nervous system is an inalienable part of the whole nervous system and that the influences on the processes operating in the internal organs are determined by the cerebral cortex.

The state of the vegetative nervous system is also influenced by certain hormones and various medicinal substances. For example, adrenalin raises the tone of the sympathetic division:

**Concept of mediators.** Excitation of the vegetative nervous system is accompanied by secretion in the nerve endings of special chemical substances called *mediators* (transmitters). The nerve endings of the sympathetic nerve fibres located in the tissues produce a substance called *sympathin* (similar to *epinephrine*); the endings of the parasympathetic fibres produce acetylcholine. The excitation is transmitted from the nerve fibres to the organs through these substances.



## *Sense Organs*

### GENERAL INFORMATION

All stimuli acting on the organism are perceived by sensory nerve endings, called **receptors**, imbedded in the special sense organs (eyes, ears), and in all the other organs of the human body (skin, muscles, internal organs, etc.). Receptors adapted to perceive particular stimuli, such as optic, colour, thermal stimuli, etc., appeared in animals and in man during the process of evolution. The excitation caused by stimulation of the receptors reaches the cerebral cortex where it produces sensations, such as pain, heat, vision, hearing, etc. Thus we perceive and determine the objects of the external world, which exist independently of us.

Pavlov developed the theory of analysers as the result of his studies on the activity of the cerebral cortex. According to this theory, an **analyser** is a single functional system consisting of three parts: (1) a peripheral part or receptor, (2) a conducting part, and (3) a central or cerebral part. The *peripheral part* of an analyser consists of sensory nerve endings, i.e., receptors which perceive definite stimuli. The conducting part consists of sensory nerve fibres, and the excitation arising in the receptors passes along these to the cerebral cortex. The *central part* or, according to Pavlov, the cerebral end of the analyser, is located in the cerebral cortex. Here the finest and highest analysis of the excitation takes place and a sensation is produced. For example, the visual analyser consists of a peripheral part, which is the eye, a conducting part, which is the optic nerve, and a central part, which is the area in the cortex of the occipital lobe of the hemisphere. Optic stimuli are perceived in the retina of the eye. The excitation arising there is transmitted along the optic nerve to the cerebral cortex. In the cerebral cortex the optic stimuli are analysed

and visual sensations arise. For a sensation to arise all parts of the analyser must function normally. If even one of these parts is not functioning properly, perhaps as a result of injury or disease, the activity of the entire analyser will be disturbed. For example, disease of the retina of the eye, or injury to the optic nerve impairs vision.

It follows from the above that the sense organs or receptors are the peripheral parts of analysers. All receptors are usually divided into two groups: receptors which perceive stimuli arising within the organism, which are called interoceptors, and receptors perceiving stimuli in the external environment, the exteroceptors.

**Interoceptors** have been found in all the internal organs: the heart, stomach, intestines, spleen, blood vessels, etc. They perceive stimuli giving information on the processes operating in the internal organs. For example, in the walls of the blood vessels there are receptors which become excited when there are changes in the blood pressure or in the chemical composition of the blood. Pavlov pointed out that the sensitivity of the internal organs is very important to the regulation of their activity. The automatic regulation of cardiovascular activity is due to the presence of sensory nerves and their endings in the heart and blood vessels.

The sensory nerve endings in the muscles, tendons, ligaments and joint capsules are called **proprioceptors**. Changes in muscular tension, the stretching of ligaments, joint capsules and tendons, and other stimuli give rise to excitation in the proprioceptors; the excitation is transmitted to the spinal cord and brain where it produces sensations giving the position of the whole body and its various parts in space, and thus co-ordinating the movements.

Disturbances in musculo-articular sensitivity impair the gait and other movements. Patients with such disturbances cannot determine the position of the affected parts of the body when their eyes are closed.

**Exteroceptors** perceive stimuli in the external environment. The exteroceptors include the skin receptors and the organs of taste, smell, vision, hearing and balance.

### CUTANEOUS SENSITIVITY

The skin contains a large number of receptors (Fig. 148); they are endings of sensory nerve fibres. There are pain, temperature (heat and cold) and tactile skin receptors.

Stimulation of the **pain receptors** gives rise to excitation which is transmitted along sensory nerves and nervous pathways to the brain: a **sensation of pain** arises in the cerebral cortex. The sense of pain is very important because pain signals disturbances in the organism. The stimulation of pain receptors evokes reflex changes, such as in-

creased secretion of adrenalin, elevation of blood pressure and other phenomena. Certain substances, such as a procain solution, deaden the sensitivity of the pain receptors. This property is made use of in surgical operations.

Stimulation of the **temperature receptors** of the skin evokes **sensations of heat and cold**. The temperature receptors are distributed une-

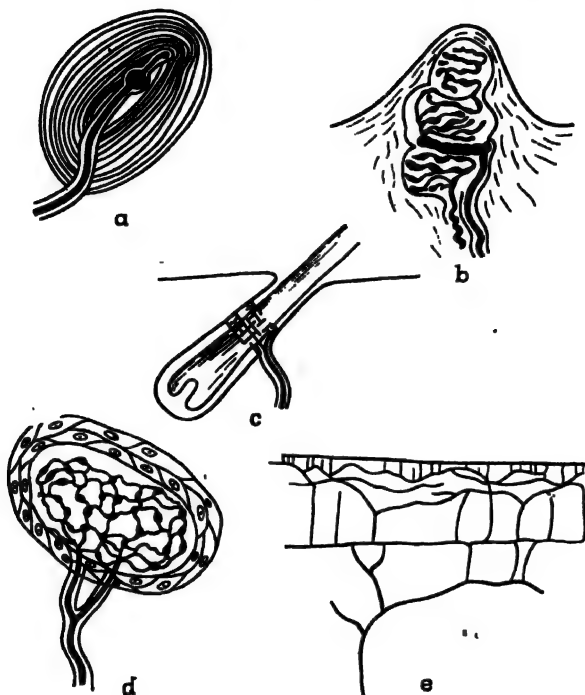


Fig. 148. Skin receptors  
a, b, c, d and e—different types of skin receptors

qually over the skin. When they are stimulated the lumens of the blood vessels change reflexly (they dilate under the action of heat and become constricted under the action of cold) so that the amount of heat emitted is altered.

Other organs, besides the skin, also have temperature and pain receptors.

The **tactile receptors** perceive contact with and pressure on the skin. Because of this we can determine the shape, size and hardness of objects (this feeling is particularly well developed in the blind).

Tactile receptors are not equally distributed throughout the body. They are especially plentiful in the tips of the fingers, in the skin of the palms of the hands, and on the tip of the tongue. The **sense of touch** resulting from stimulation of various receptors of the skin, particularly the tactile and temperature receptors, produces a complex sensation.

### ORGAN OF TASTE

The organ of taste is represented by the so-called **taste buds** which are located in the taste papillae of the tongue, in the soft palate and

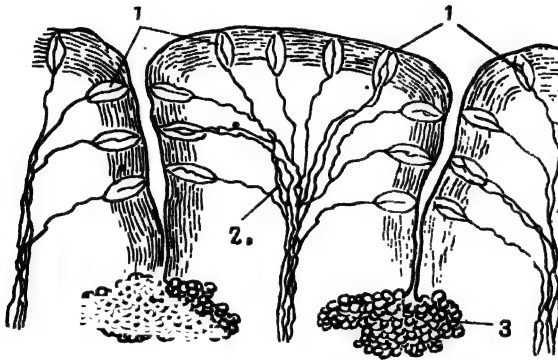


Fig. 149. Diagram showing structure of taste papilla  
1—taste buds; 2—nerve fibres giving off from taste buds; 3—mucous glands

in the pharynx. The taste buds consist of special cells near which gustatory (sensory) nerve fibres terminate (Fig. 149). Food substances in the oral cavity come into contact with the taste buds and give rise to excitations in the endings of the gustatory nerves; the resultant excitations are transmitted to the brain. The nerve impulses are transmitted along the sensory nerve fibres which form part of the chorda tympani and the glossopharyngeal nerve. Taste sensations arise in the cerebral cortex; the cerebral part of the gustatory analyser is located in the temporal lobe. Various food reflexes, such as salivation and the secretion of other digestive juices, are associated with the perception of gustatory stimuli. The character of the food (whether edible or not) is also determined by taste.

There are four types of taste sensation: sensation of sweet, bitter, salt, and sour. All the other taste sensations are combinations of these basic sensations.

It should be remembered that the taste buds are stimulated only by food substances in a dissolved state. Their solvent in the oral cavity is the saliva.

### ORGAN OF SMELL

The organ of smell is composed of special sensory cells located in the mucous membrane of the upper part of the nasal cavity. The processes of these cells are filaments of the olfactory nerve which enters the cranial cavity through openings in the horizontal plate of the ethmoid bone. The olfactory cells are stimulated by odoriferous substances. The resultant excitation is transmitted along the olfactory nerve to the brain where corresponding sensations arise. The cerebral part of olfactory analyser is located in the cortex of the temporal lobe. The quality of food may be determined by its smell. During eating olfactory sensations supplement taste sensations. When olfaction is disturbed, for example in cases of rhinitis, the ability to determine taste is impaired and the food seems tasteless. When certain substances, such as aromatic spirits of ammonia, chloroform and ether are inhaled, they stimulate the olfactory cells and also the endings of the trigeminal nerve in the mucous membrane of the nose. The result is not only a sensation of smell but also a reflex change in respiration (holding the breath, sneezing, etc.). Man's sense of smell is very acute. For example, he can detect the smell of hydrogen sulphide in a 1 : 100,000,000 concentration. In some animals, for example, dogs, sensitivity is even greater.

### ORGAN OF VISION

The organ of vision is the eye (oculus) which consists of the eyeball and an accessory apparatus.

The eyeball (bulbus oculi) is located in the orbit. It consists of membranes, a crystalline lens, a vitreous body and the aqueous humour.

The eyeball has three membranes—outer, middle and inner (Fig. 150).

The outer membrane is called the *tunica fibrosa oculi*. It consists of two parts: the anterior part, called the *cornea*, and the posterior part, called the *sclera*. The cornea is transparent and has no blood vessels, but is supplied with sensory nerve endings. The sclera resembles boiled egg-white in colour and contains few blood vessels.

The middle membrane of the eyeball contains a large number of blood vessels. It is therefore called the *tunica vasculosa bulbi oculi*. It consists of three parts: the anterior part or iris, the middle part or ciliary body, and the posterior part or choroid. The iris looks like a ring with a round opening, the *pupil*, in the centre. The iris is co-

loured, the colour depending on the amount of pigment it contains. Inside the iris there are smooth muscle fibres forming two muscles, the sphincter pupillae which constricts the pupil and the dilator pupillae which dilates it. The *pupil* appears black because the rays

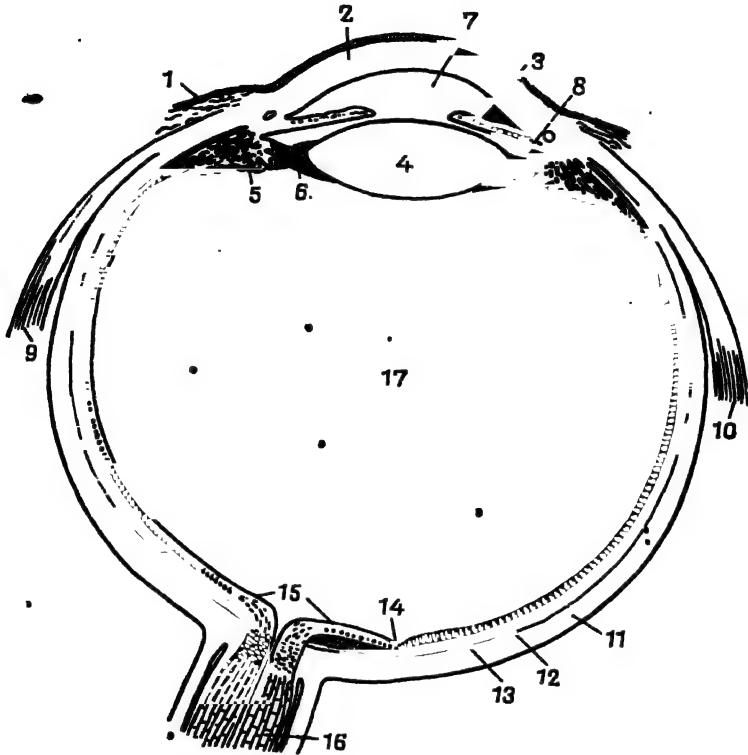


Fig. 150. Horizontal section of the eye (diagram)

1—conjunctiva; 2—cornea; 3—Iris; 4—crystalline lens; 5—ciliary body; 6—ligament attaching crystalline lens to the ciliary body; 7—anterior chamber of eye; 8—posterior chamber of eye; 9 and 10—muscles of eyeball; 11—sclera; 12—tunica vasculosa oculi; 13—retina; 14—macula lutea; 15—optic disc (optic papilla); 16—optic nerve; 17—vitreous body

of light entering the eyeball are not reflected. The size of the pupil varies with the degree of lighting: when the lighting is bright it becomes constricted and when the lighting is weak it dilates. The *ciliary body* has processes on its internal surface called *ciliary processes*. The ciliary body contains smooth muscle fibres which compose the ciliary muscle; this muscle is concerned with changing the curve of the crystalline lens. The *tunica vasculosa oculi* forms the greater

part of the middle membrane of the eyeball; besides blood vessels it contains a large amount of pigment.

The **inner membrane** is called the **retina**; it has a complex microscopic structure and perceives optic stimuli. It contains special cells, called *rods* and *cones*. The posterior part of this membrane is called the *fundus oculi*. Two small areas, the *macula lutea* and the *optic disc* (or *optic papilla*), may be distinguished in the fundus oculi. The macula lutea contains a large number of cones and is the site of clearest vision. To get the best view of an object, the eyes are moved into such a position that the rays of light fall on the macula lutea. The optic disc is the site where the optic nerve emerges from the retina. This area contains no rods or cones, does not perceive rays of light, and is called the *blind spot*. Impulses from the retina of the eye are transmitted along the optic nerve to the brain.

The **crystalline lens** is a biconvex organ. It has no blood vessels, is transparent, and possesses the ability to refract rays of light. It is fastened to the ciliary body by a special ligament. The curve of the lens may change, enabling the eye to see objects at different distances.

The **vitreous body** is located behind the crystalline lens and consists of a transparent gelatinous substance.

The **aqueous humour** is a transparent fluid located in the chambers of the eye. The eyeball has two chambers: an anterior chamber between the cornea and the iris, and a posterior chamber between the iris and the lens. The aqueous humour is under certain pressure which is called the *intra-ocular pressure*. In the disease called glaucoma the intra-ocular pressure is increased.

The **accessory apparatus of the eye** consists of protective, lacrimal and motor parts. The **protective part** includes the eyebrows, eyelashes and eyelids. The *eyebrows* prevent sweat running down the forehead from getting into the eyes. The *eyelashes* are situated on the free border of the eyelids and stop dust particles. Each *lid* consists of dense connective tissue (externally it resembles cartilage) and is covered by skin on the outside and by a pink-coloured membrane on the inside. This membrane is called the *conjunctiva* (inflammation of the conjunctiva is called conjunctivitis). The conjunctiva of the lids is continuous with the conjunctiva of the anterior portion of the eyeball, but does not cover the cornea. When the lids are closed there is a narrow space, the *conjunctival sac* between the lids and the eyeball. The skin of each lid contains so-called Meibomian (or tarsal) glands whose ducts open on the free borders of the lids.

The **lacrimal part** (Fig. 151) consists of a lacrimal gland and lacrimal ducts. The *lacrimal gland* is located in the lateral upper corner of the orbit and its *ducts* open into the superior portion of the conjunctival sac. The tears bathe the anterior part of the eyeball and prevent the cornea from drying. The blinking movements of the

eyelids help to moisten the cornea. The tears accumulate at the medial canthus near the *lacrimal caruncle*. Here the upper and lower lids each have a small orifice (*puncta lacrimalia*) which is the beginning of the *lacrimal canaliculus* which opens into the lacrimal sac.

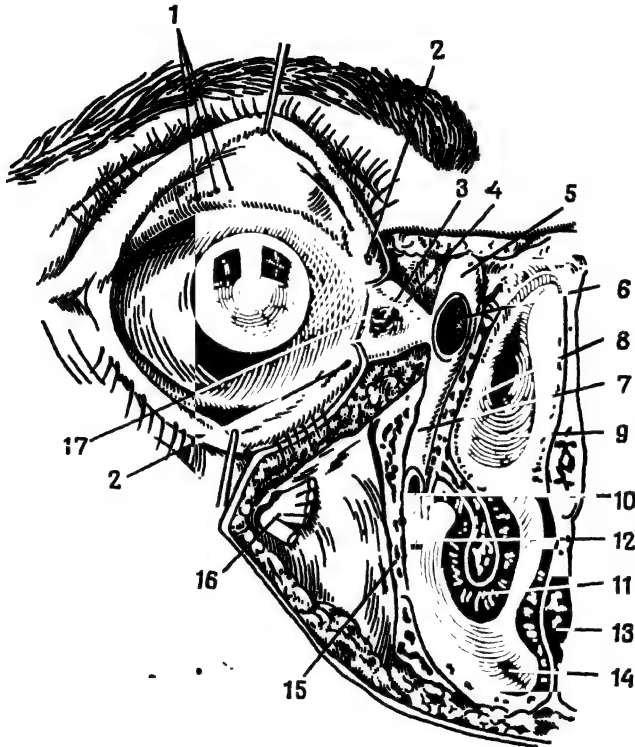


Fig. 151. Lacrimal apparatus

1—openings of excretory ducts of lacrimal gland; 2—puncta lacrimalia; 3—lacrimal caruncle and lacrimal lake; 4—superior lacrimal canaliculus; 5 and 6—lacrimal sac (opened); 7—nasolacrimal duct; 8—middle nasal passage; 9—middle nasal concha; 10—opening of nasolacrimal duct; 11—inferior nasal concha; 12—inferior nasal passage; 13—nasal septum; 14—inferior wall of nasal cavity; 15—section of maxillary bone; 16—suborbital nerve; 17—semilunar fold

The lacrimal sac is continuous with the *nasolacrimal duct* along which the tears drain into the nasal cavity.

The motor part consists of six muscles attached to the eyeball and one muscle which raises the upper lid. Four of the eyeball muscles are *recti muscles* (*rectus oculi superior, inferior, lateral and medial*) and two are oblique muscles (*obliquus oculi superior and inferior*). The contractions of these muscles move the eyeball.



## ORIGIN OF VISUAL SENSATIONS

Optic stimuli are perceived by the retina of the eye which is the receptor part of the visual analyser. Before reaching the retina the rays of light go through the transparent refractive media of the eyes, i.e., through the cornea, aqueous humour, crystalline lens and vitreous body. The rays are refracted most in the lens. The eyeball is usually compared with a camera in which the crystalline lens acts as the lens and the retina is the photosensitive plate. In the retina

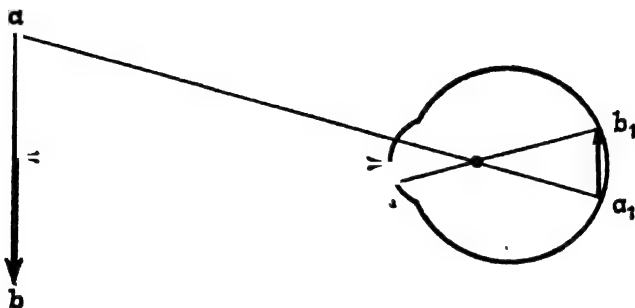


Fig. 152. Path of light rays forming an image in the eye  
*a*—superior point of object; *a*<sub>1</sub>—its image on the retina of the eye; *b* and *b*<sub>1</sub>—inferior point of object and its image on the retina

of the eye the objects viewed appear diminished and turned upside down (Fig. 152).

The rods and cones are the photosensitive elements in the retina. The cones have been found to be associated with diurnal vision and the rods with nocturnal and twilight vision. The rods contain a special substance known as *visual purple* or *rhodopsin*. This substance is formed with the participation of vitamin A. Disturbance in the formation of visual purple leads to so-called *nyctalopia* (night blindness).

The rays of light reaching the retina stimulate the rods and cones. The resultant excitation is transmitted along the optic nerve to the brain. The optic stimuli are perceived in the cerebral cortex and visual sensations arise. The cerebral part of the visual analyser is located in the occipital lobe of the cerebral hemispheres.

**Colour sensation.** The eye's ability to distinguish colour is due to the fact that the cones of the retina have special substances which are sensitive to various colours.

Some people suffer from disturbances in colour sensation, resulting in generally weak colour sensation, loss of sensation of particular colours or complete loss of colour sensation. For example, some people cannot distinguish light-brown from dark-green, or purple and violet

from blue. This form of colour-blindness is called *daltonism* (after Dalton). Special coloured tables are used to test colour vision.

**Adaptation of the eye.** The human eye can adapt itself to seeing objects under lighting of various intensities. This ability is called adaptation. Under bright lighting the optic stimuli are perceived only by the cones (diurnal vision); all of the visual purple in the rods is destroyed and they do not function. If bright lighting is quickly replaced by darkness, man cannot at first see at all. The visual purple is gradually restored in the rods of the retina, and twilight vision appears.

**Accommodation.** The human eye can see objects at different distances. This adaptation of the eye is called accommodation; it is made possible by the ability of the lens to change its curvature because of its elasticity. When near objects are viewed the lens is more convex than when far objects are viewed. The change in the curvature of the lens is accompanied by a change in its refractive power, so that the rays of light from the object are always focused in the retina. In optics the refractive power of a lens is measured by a special unit, the *dioptr*. The refractive power of a lens with a focal length of 1 m is 1 *dioptr*.

The changes in the curvature of the lens depend upon the contractions and relaxations of the ciliary muscle. When this muscle contracts the ligament attaching the lens to the ciliary body relaxes, and the lens becomes more convex. This occurs when near objects are viewed.

When the ciliary muscle relaxes, the lens becomes less convex. This occurs when far objects are viewed.

**Myopia** (shortsightedness) and **hypermetropia** (farsightedness). Some people have visual disturbances which result in the images of objects being unclear and vague. Such images are produced when the rays from the object are focused not on the retina, but in front of it or behind it. In cases of myopia the focus is in front of the retina, and in cases of hypermetropia the focus is behind the retina (Fig. 153). Both myopia and hypermetropia are due to disturbances in accommodation or to characteristics in the structure of the eyeball. In myopic people the distance from the lens to the retina is usually

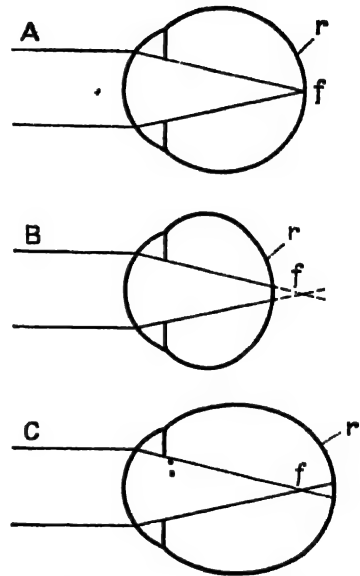


Fig. 153. Myopia and hypermetropia

A—normal eye; B—hypermetropic eye; C—myopic eye; *r*—retina; *f*—focus of parallel rays

somewhat longer than normal, while in hypermetropic people it is shorter. To obtain clear images, such people wear spectacles with the necessary lenses.

**Visual acuity.** Visual acuity implies the shortest distance between two luminous points at which they are perceived by the eye separately.

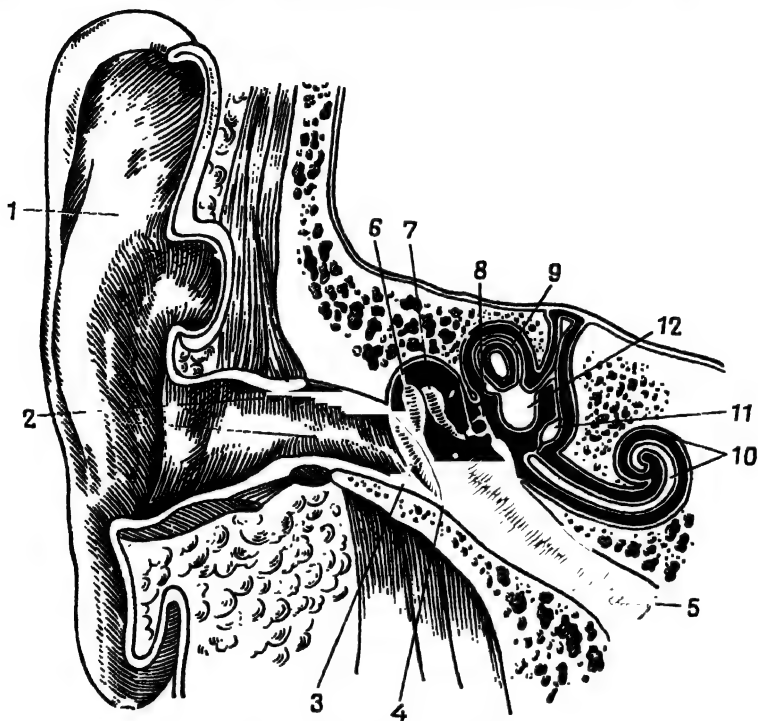


Fig. 154. Section of ear

1—pinna of ear; 2—external auditory canal; 3—tympanic membrane; 4—cavity of middle ear; 5—auditory tube; 6—malleus; 7—incus; 8—stapes; 9—semicircular canal; 10—cochlea; 11—saccule; 12—utricle

tely. Special tables with figures, letters, or other signs arranged in several rows are used to determine the acuity of vision. The figures in each row are of exact size corresponding to the definite visual acuity. Complete visual acuity is determined for each eye separately, with the subject at a distance of 5 m from the table.

#### ORGAN OF HEARING AND BALANCE

The ear (Fig. 154) perceives not only acoustic stimuli, but also stimuli caused by changes in the position of the body in space; it is therefore called the organ of hearing and balance.

The ear is divided into three parts: the external ear, the middle ear, and the internal ear.

The **external ear** consists of the pinna and the external auditory canal. The *pinna of the ear* is formed by an elastic cartilage covered with skin (only the lower part of the pinna, the *earlobe*, has no cartilage). It has four parts: *helix*, *anthelix*, *tragus* and *antitragus*.

The *external auditory canal* is a short, curved structure. It is lined with skin containing glands which secrete ear wax. The external auditory canal is separated from the middle ear by the *tympanic membrane* made of resilient connective tissue. On the side of the external auditory canal the tympanic membrane is covered with very thin skin, and on the side of the middle ear it is covered with a mucous membrane.

The **middle ear** is a cavity with volume of about 1 cu cm, located in the petrous pyramid. It contains a chain of three *auditory ossicles*, called the *malleus*, *incus* and *stapes*. The cavity of the middle ear is called the *tympanic cavity*. It is lined with a mucous membrane. Six walls are distinguished in the cavity of the middle ear; the tympanic membrane constitutes the outer wall, while the other walls are osseous. Above the tympanic cavity is the *middle cranial fossa*, below is the *jugular foramen*, in front is the *carotid canal*, behind is the *mastoid process*, and inside is the *internal ear*. The internal wall of the middle ear has two apertures, one *round* and one *oval*. The round aperture, the fenestra cochleae or fenestra rotunda, is covered by a membrane (called the *secondary tympanic membrane*); the oval aperture, the fenestra vestibuli or fenestra ovalis, is covered by the stapes. The tympanic cavity communicates with the nasopharynx through the *auditory tube* (*Eustachian tube*). A special orifice links it with the mastoid cells.

The auditory tube is 3.5-4 cm long with a lumen 2 mm across. It consists of osseous and cartilaginous parts. The osseous part is located in the musculotubal canal of the temporal bone, and the cartilaginous part is located on the lateral surface of the base of the skull (sphenoid bone). The tube is lined with a mucous membrane.

Air reaches the tympanic cavity through the auditory tube, so that the pressure on both sides of the tympanic membrane is the same. The auditory tube may provide a route for infection to pass from the nasal cavity and nasopharynx into the middle ear\*.

The **internal ear** is located in the petrous pyramid. It has a complicated form and is therefore also called the *labyrinth*. There are two labyrinths, the *osseous* and *membranous* labyrinths (Fig. 155).

The *osseous labyrinth* consists of three parts: the *cochlea*, the *vestibule*, and *three semicircular canals*. The cochlea makes two-and-a-

\* Inflammation of the middle ear is called *otitis media*.

half turns about a bony axis called the modiolus. The vestibule is situated between the cochlea and the semicircular canals, and is an oval-shaped cavity. The semicircular canals lie perpendicularly to each other.

The *membranous labyrinth* lies inside the osseous labyrinth and is of almost the same shape, but somewhat smaller. The walls of the membranous labyrinth are composed of dense connective tissue.

The *osseous vestibule* contains two *membranous vesicles* called the *sacculle* and the *utricle*, the *osseous cochlea* contains a *membranous canal*, and the *osseous semicircular canals* contain *membranous semi-*

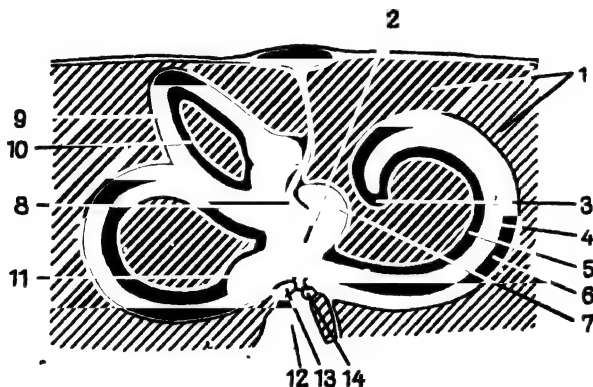


Fig. 155. Structure of the osseous and membranous labyrinths

1—petrous pyramid; 2—vestibule; 3—communication between scala vestibuli and scala tympani; 4—membranous cochlear canal; 5—scala vestibuli; 6—scala tympani; 7—sacculle; 8—utricle; 9—membranous semicircular canal; 10—osseous semicircular canal; 11—membranous ampulla; 12—tympanic cavity, 13—fenestra ovalis (fenestra vestibuli); 14—fenestra rotunda (fenestra cochleae)

*circular canals*. Between the osseous and membranous labyrinths is a fluid called the *perilymph*; the membranous labyrinth also contains a fluid called the *endolymph*. In the cochlea the space containing perilymph is divided into two parts by a special bony plate. These parts are called the *scala tympani* and the *scala vestibuli*. The scalae communicate with each other only at the apex of the cochlea.

The *spiral lamina* of the membranous canal of the cochlea contains the *spiral organ* (*organ of Corti*) (Fig. 156). This organ has a complicated structure and consists of cells of different types. It is the *sound-perceiving apparatus*. Fibres from the cochlear nerve which is part of the acoustic nerve end on the cells of this organ.

On the inner surface of both the membranous vesicles of the vestibule and the membranous semicircular canals there are special struc-

tures called *maculas*, and *cristae* which contain sensory cells. The vestibule and semicircular canals together form the *vestibular apparatus*, the organ which perceives the position and movements of the body in space. Fibres of another part of the acoustic nerve, called the vestibular nerve, extend to the sensory cells of the vestibular apparatus.

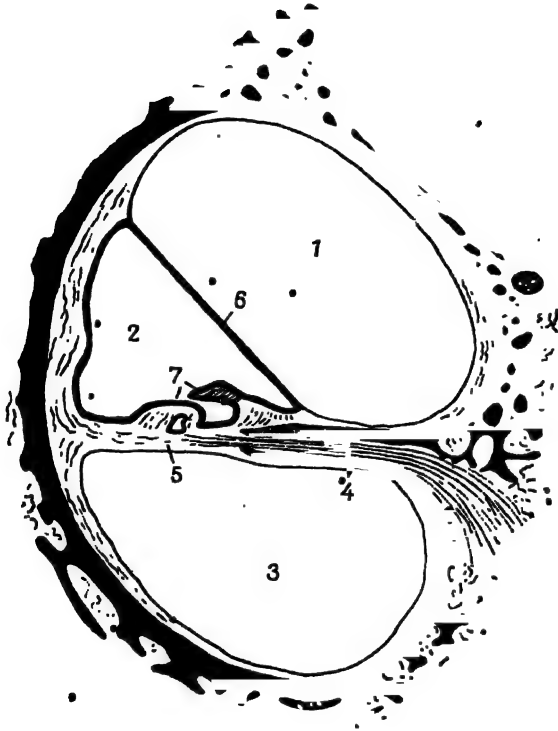


Fig. 156. Diagram of transverse section of cochlea (greatly magnified)  
 1—scala vestibuli; 2—membranous cochlear canal; 3—scala tympani; 4—spiral osseous lamina; 5—basilar membrane; 6—vestibular membrane; 7—organ of Corti

### ORIGIN OF AUDITORY SENSATIONS

The external and middle ears perform a sound-conducting function, and the organ of Corti in the internal ear performs a sound-perceiving function. The organ of Corti contains receptors which perceive acoustic stimuli.

The vibrations of the air are called sound. Air vibrations pass through the external auditory canal, reach the tympanic membrane,

and make it vibrate. The vibrations of the tympanic membrane are transmitted to the auditory ossicles and then to the perilymph in the internal ear. The vibrations of the perilymph in their turn cause vibrations of the endolymph through the wall of the membranous canal of the cochlea; the vibrations of the endolymph are then transmitted to the organ of Corti.

The spiral lamina of the organ of Corti consists of fine fibrils which are stretched like the strings of a musical instrument. The fibrils are of various lengths and it is believed that they are tuned for definite sounds. High-pitched sounds cause vibrations of short fibrils, and low-pitched sounds cause vibrations of the long fibrils. As a result, sounds of varying pitch may be perceived.

The vibrations in the organ of Corti give rise to excitation in the endings of the cochlear nerve; this is transmitted along the acoustic nerve to the brain. The acoustic stimuli are perceived in the cerebral cortex and auditory sensations arise. The cerebral end of the auditory analyser is located in the temporal lobe.

#### **ORIGIN OF SENSATIONS OF BODY POSITION AND MOVEMENT**

The position and displacement of the body in space are perceived by various sense organs—visual receptors, tactile receptors, proprioceptors, etc.

The vestibular apparatus plays an important part in producing sensations of body position and movement. The receptors of the vestibular apparatus, which perceive the changes in the position of the body in space, are imbedded in the maculas and cristae which are located in the membranous vesicles of the vestibule and in the membranous semicircular canals. Changes in the position of the head and in the speed of movement are accompanied by changes in the pressure of the endolymph on the sensory cells of the maculas and cristae. This produces excitation in the vestibular nerves, which is transmitted along the acoustic nerve to the brain. In the cerebral cortex a sensation of the position of the body in space arises. A reflex change in the tone of various groups of muscles occurs simultaneously. The position of the head and body changes as a result of muscular contraction, so that the body maintains its balance.

The role of the vestibular apparatus can be determined by experiments on animals. Animals whose vestibular apparatus has been destroyed lose the ability to maintain their balance.

If the vestibular apparatus in man is damaged, there will be disturbances in movement, dizziness and other disorders. Some people suffer from motion sickness (become dizzy, vomit, etc.) when they travel by boat, car or plane. Motion sickness is usually due to increased excitability of the vestibular apparatus.

## *Skin*

The skin (cutis) is the outer covering of the human body. It has a complicated microscopic structure and carries out many functions.

### STRUCTURE OF THE SKIN

The skin consists of two layers, *superficial* and *deep* (Fig. 157).

The superficial layer of the skin is called the **epidermis**. It consists of *stratified epithelium*. Epithelial cells multiply continuously in the deep layer of the epidermis, and so it is called the **stratum germinativum**. In the superficial layer of the epidermis the cells gradually keratinize and peel off. This layer is called the **stratum corneum**.

The deep layer of the skin is called the **true skin** (corium, or derma). It consists of dense fibrous connective tissue and contains a large number of *collagenous* and *elastic fibres*; the latter impart elasticity to the skin so that it can easily move and stretch, and then resume its original state. The connective-tissue fibres of the true skin interlace and form networks, but in each portion of skin the connective-tissue bundles lie in a basic direction. This is taken into account in surgical practice when incisions have to be made in the skin; to prevent the edges of the wound from parting, the incisions are made parallel to the basic direction of the connective-tissue fibres. The deep layer of the skin has a large number of blood vessels, and the capillaries form vascular networks. A large amount of blood may be deposited in these networks. At the border with the epidermis the true skin forms projections, or **papillae** (**papillary layer of the skin**). The surface of the skin therefore has ridges (cristae) with



fissures in between: their sizes and correlation in the different parts of the body differ from person to person.

The true skin is continuous with the underlying *subcutaneous tissue*. The subcutaneous tissue consists of loose connective tissue containing deposits of fat. The amount of fat in the subcutaneous

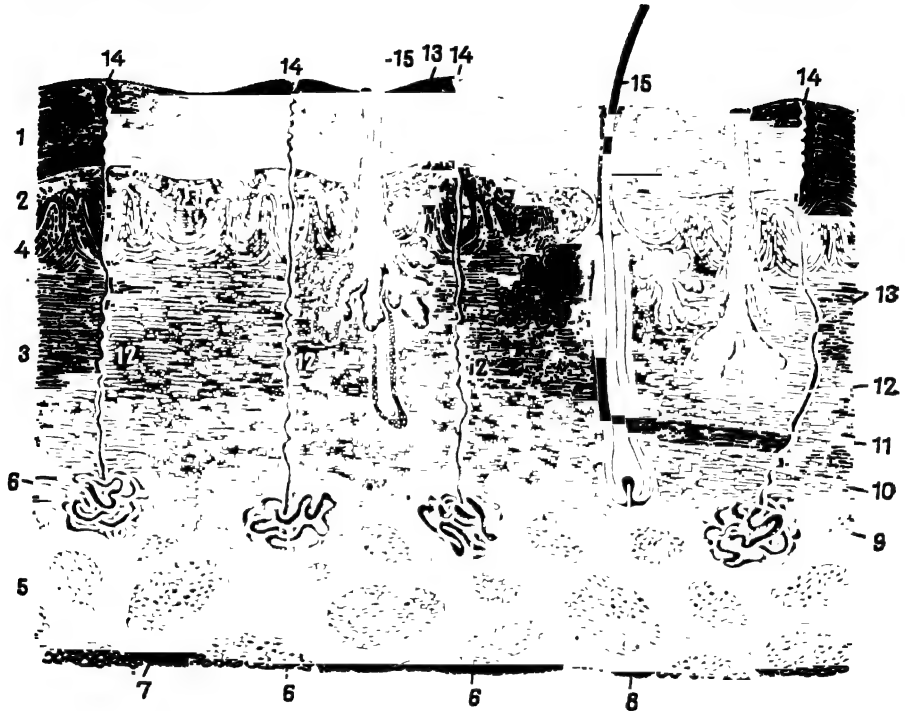


Fig. 157. Skin (vertical section)

1—stratum corneum; 2—stratum germinativum; 3—true skin (corium or derma); 4—papillary layer of true skin; 5—subcutaneous tissue; 6—sweat glands; 7—accumulations of fat cells; 8—hair papilla; 9—hair bulb; 10—hair root; 11—hair follicle; 12—duct of sweat gland; 13—sebaceous gland; 14—sweat pore (opening of sweat gland duct); 15—hair shaft

layer varies with the individual. In females this layer, as a rule, contains more fat than it does in males. The thickness of the adipose layer differs in the different parts of the human body. No fat is deposited in the eyelids, the pinnae of the ears, or on the sex organs.

The subcutaneous adipose tissue safeguards the underlying organs (muscles, etc.) against mechanical injury. The fat deposited under the skin serves as a reserve nutritive material.

The total surface area of skin in an adult averages 1.5 sq m. The

thickness of the skin ranges from 1 to 4 mm. The thinnest skin is on the eyelids, and thickest is on the soles of the feet.

The colour of the skin is determined by the pigment it contains. The various shades of skin colour in the different people depend on the amount of pigment in the skin. Under the influence of ultraviolet rays (sunlight, mercury quartz lamp) the deposition of pigments in the skin increases.

Medicines are sometimes administered intracutaneously and very often subcutaneously. Subcutaneous injections are made in places where there are no large blood vessels or nerves (the posterolateral surface of the upper arm and the lateral surface of the thigh).

**Skin glands.** The skin contains a large number of sweat and sebaceous glands.

The **sweat glands** are located in the deep layer of the true skin and in subcutaneous tissue. Each gland takes the form of a coiled tube. Its excretory duct opens onto the surface of the skin as a small orifice, or pore. Man has a total of close to two million sweat glands. They are especially plentiful on the palms of the hands and the soles of the feet. The secretion of the sweat glands, the *sweat*, contains water, common salt, urea and other substances. An average of 500-600 ml of sweat is excreted every 24 hours. The intensity of perspiration may vary under different conditions—temperature and humidity of the air, physical work, etc. Evaporation of sweat from the surface of the skin is one of the ways heat is lost. During strenuous physical work in a hot climate the daily amount of sweat may reach 15 litres.

The skin of the axillae, symphysis pubis, and external genitalia contains glands which are structurally similar to sweat glands. They secrete a substance with a specific odour.

The **sebaceous glands** are located in the true skin all over the surface of the body, except for the palms of the hands and the soles of the feet. The excretory ducts of these glands, as a rule, open into hair sacs. Only in some places, for example on the vermilion border of the lips, do they open on the surface of the skin. The sebaceous glands secrete *sebum* which lubricates the hair and the skin. The secretion of sebum decreases in old age, and the skin and hair become dry.

**Appendages of the skin.** The appendages of the skin are the hair and nails.

The **hair** covers a considerable part of the skin. It is absent on the palms of the hands, soles of the feet and certain other parts of the body. The trunk and extremities are covered with thin hair (fluff). The hair of the eyebrows and eyelashes is short and bristly. Long hair grows on the head, in the axillae, on the symphysis pubis and, in males, also on the skin of the face (moustache and beard). The

colour of the hair is due to a special pigment. In old age (and sometimes at a young age) the hair gradually loses its pigment and becomes grey.

A hair consists of a *shaft* and a *root*. The shaft is above the skin and the root is in the skin. The thickened part of the hair root is called the *hair bulb*. It has a recess which contains the *hair papilla*. Hair is composed of altered keratinized cells of cutaneous epithelium. Only the cells of the hair bulb contain no keratin; these cells continuously multiply. The hair grows from the hair bulb. The hair papilla is composed of connective tissue and contains blood capillaries which nourish the hair bulb. The hair root is surrounded by a hair sac which consists of cutaneous epithelium and connective tissue. The ducts of sebaceous glands open into hair sacs.

Smooth muscle fibres are attached to the hair roots. When the muscle fibres of the skin contract the hair stands up on end and small prominences ("goose flesh") appear on the surface of the skin.

The *nails* are hard, horny, and slightly curved plates. They have a protective function. A nail consists of a *root* and a *body*, the latter having a free edge. The body and root of the nail lie in the *nail bed* and are fused with the skin. The skin of the nail bed is abundantly supplied with sensory nerve endings and blood vessels. The root and lateral parts of the nail body are covered with a fold of skin, called the *nail fold*. The nails grow continuously all through life; they grow from the *stratum germinativum* in the region of the root.

### FUNCTIONS OF THE SKIN

The skin has a **protective function**; it safeguards the organism against certain harmful influences in the external environment. It protects the underlying organs from mechanical injury. No microbes or any harmful substances can penetrate through healthy skin. Microbes entering through injured portions of the skin may cause inflammation.

The skin also performs an **excretory function**; various waste products (urea, salts, etc.) are eliminated with the sweat through the skin. The secretion of the sebaceous glands (sebum) lubricates the skin and the hair.

The skin takes part in **thermoregulation**; heat is emitted into the external environment through the skin (by radiation, conduction, and with the sweat). The amount of heat emitted depends on various factors (temperature and humidity of the air, physical work, etc.). When the blood vessels in the skin are dilated, more blood flows through them and heat emission increases; when the blood vessels are constricted heat emission decreases.

The skin also performs the function of a **sense organ**, it contains

many sensory nerve endings which perceive various stimuli in the external environment (see "Sense Organs").

The resistance of the organism may be enhanced by toughening the skin. The skin may be hardened by exposure to the sun and wind, and by various methods using water, etc.

### MAMMARY GLAND

The mammary gland (mammary) is like a modified and greatly enlarged sweat gland of the skin.

This paired organ which looks like a hemisphere (Fig. 158) is located at the level of the third-sixth ribs.

The mammary gland has a small projection, the **nipple**, surrounded by a portion of pigmented skin called the **mammary areola**. The shape and size of the gland vary with the individual, and change with age and during pregnancy.

The mammary gland grows intensively in girls during sexual maturation. A fully-developed gland consists of 15-20 radially arranged glandular lobules interconnected by fat containing connective tissue. Each lobule consists of numerous smaller lobules with excretory ducts called **milk** or **lactiferous ducts**. The smaller ducts coalesce into larger ones which open in 8 to 15 orifices on the nipple; before opening on the nipple they form dilations called **lactiferous sinuses**. Periodical changes (growth of glandular epithelium) occur in the mammary gland in connection with ovulation in the ovaries. The mammary gland attains its greatest development during pregnancy and nursing. From the fourth or fifth month of pregnancy it begins

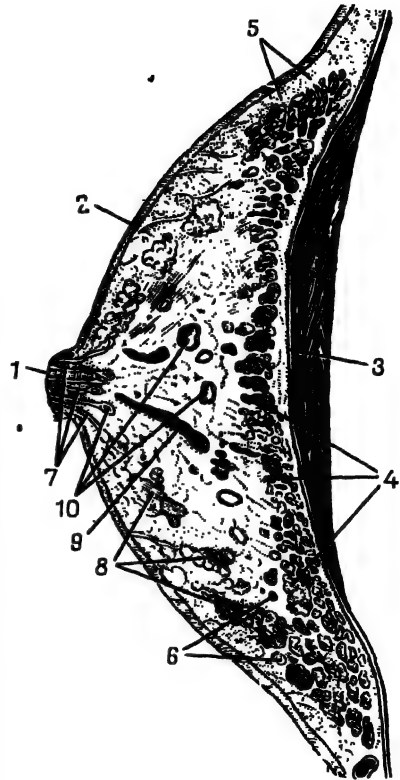


Fig. 158. Female mammary gland (section)

1—nipple; 2—skin; 3—fascia covering pectoralis major muscle; 4—body of mammary gland; 5—adipose tissue; 6—lobules of the gland; 7—lactiferous ducts; 8—lobules of the gland; 9—lactiferous sinuses (longitudinal section); 10—lactiferous sinuses (transverse section)

to secrete colostrum. After childbirth the secretory activity of the gland greatly increases and at the end of the first week the gland begins to secrete milk.

**Composition of human milk.** Milk consists of water, and organic and inorganic substances. The main constituents of human milk are fat (in the form of minute fat droplets), casein (protein), lactose (milk sugar), mineral salts (sodium, calcium, potassium, etc.), and vitamins. Human milk may contain antibodies produced by the maternal organism. Human milk is an indispensable food for the newborn. The process of milk secretion is regulated by the nervous system. This is demonstrated by the fact that the activity of the mammary glands is influenced by the psychic state of the mother and the reflexly increased milk secretion in response to the sucking of the breast by the child. The process of milk production is also influenced by hormones of the hypophysis, the ovaries and other endocrine glands. A nursing woman secretes from 1 to 2 litres of milk per day.

## *Endocrine Glands*

### GENERAL INFORMATION

Endocrine glands, or glands of internal secretion, are glands without excretory ducts. They produce special substances called hormones (from the Greek word *hormao*—I excite), which are secreted directly into the blood. The hormones are carried throughout the organism with the blood and are delivered to various organs whose activity they either stimulate or depress.

Hormones play a very important part in the organism. Many of them affect metabolism and the functioning of the cardiovascular, reproductive and other systems. A disturbance in the activity of the endocrine glands is accompanied by changes throughout the organism. These changes may be due to an increase in the function of a gland (**hyperfunction**) or a decrease (**hypofunction**). A hyperfunctioning gland secretes a superfluous amount of hormones, and a hypofunctioning gland secretes an insufficient amount\*. The chemical composition of some hormones is well known. Various hormonal preparations are made synthetically or from the corresponding glands of animals (endocrine preparations) and are increasingly widely used in medicine. It should be noted that hormones are substances with very high biological activity (some of them are effective in a 1:1,000,000 dilution). The endocrine glands include the hypophysis (or pituitary), the epiphysis cerebri (or pineal), the thyroid, the parathyroids, the thymus, the islet part of the pancreas, the adrenals and the incertory part of the sex glands (testes and ovaries) (Fig. 159). Each gland consists of glandular epithelial tissue and has an extensive network of blood vessels and a large number of nerve fibres (from the vegetative nervous system).

\* The amount of hormones produced by the endocrine glands in 24 hours measures fractions of a milligram.

The functions of all the endocrine glands are interconnected, and the glands make up a single system. The hypophysis is the chief gland of this system; it produces special substances which stimulate the activities of the other endocrine glands.

The influence of various substances (mainly hormone) acting on the organism through the blood is called humoral regulation.

The activities of endocrine glands are regulated by the nervous system. The nervous system exercises direct control over the endocrine glands through the nerves and neurohumoral control, particularly through the hypophysis. The hormones in their turn affect the functions of the different parts of the nervous system.

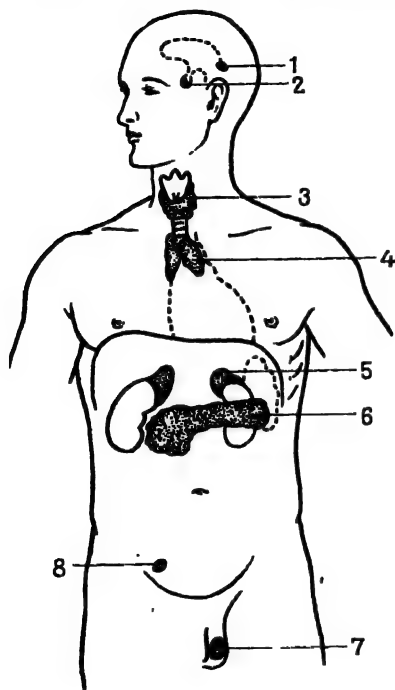


Fig. 159. Diagram showing location (in projection) of endocrine glands

1—pineal gland; 2—hypophysis; 3—thyroid and parathyroid glands; 4—thymus; 5—adrenal; 6—islet part of pancreas; 7—incretory part of testes; 8—incretory part of ovaries

### HYPOPHYSIS

The hypophysis (hypophysis cerebri) is a small oval body weighing about 0.5 g; it is located in the cranial cavity (in the sella turcica) and is connected with the hypothalamus. The gland consists of an anterior lobe, an intermediate part and a posterior lobe; the borders between them can be seen only under a microscope.

The **anterior lobe** produces several **hormones**: (1) the *somatotrophic* or *growth hormone* which influences metabolism, particu-

larly the synthesis of proteins in the tissues; (2) the *thyrotrophic hormone* which affects the thyroid gland; (3) the *adrenocorticotrophic hormone* (ACTH) which stimulates the function of the adrenal glands; and (4) the *gonadotrophic hormone* which affects the sex glands.

The hypothalamus has been found to secrete special substances, which regulate the secretion of the hypophyseal hormones. The activities of the other endocrine glands are thus subject to neurohumoral regulation through the hypophysis.

*Dysfunction* of the anterior lobe of the hypophysis is accompanied by changes throughout the organism. For example, excessive secretion of the growth hormone in childhood results in *gigantism* (Fig. 160). Persons with abnormal growth may reach a height of 2.5-2.6 m. Excessive secretion of this hormone in adults results in excessive growth of the bones of the face, fingers and toes, and an enlarged nose, tongue, and certain other organs. This disease is called *acromegaly*. Insufficient secretion of the growth hormone in childhood is accompanied by retarded growth (*dwarfism*).

The **posterior lobe** of the hypophysis secretes oxytocin and vasopressin. *Oxytocin* intensifies the contractions of the uterine muscles and is therefore used to boost weak labour. *Vasopressin* causes constriction of the blood vessels, especially those of the uterus. An active substance which possesses antidiuretic activity (antidiuretic hormone) has been isolated from vasopressin. It causes increased absorption of water into the blood in the uriniferous tubules so that less urine is produced. Hypofunction of the posterior lobe of the hypophysis causes a decrease in the secretion of the antidiuretic hormone and is accompanied by disturbances in water metabolism called *diabetes insipidus*. This disease is characterized by intense thirst (patients drink around 20 to 30 litres of water per day) and the passage of a large quantity of urine.

*Pituitrin*, an extract from the posterior lobe of the hypophysis, which contains hormones, is used in medical practice.

It is now thought that the hormones secreted by the posterior lobe of the hypophysis are produced not in the hypophysis, but in the nerve nuclei of the hypothalamus whence they are deposited in the posterior lobe of the hypophysis.

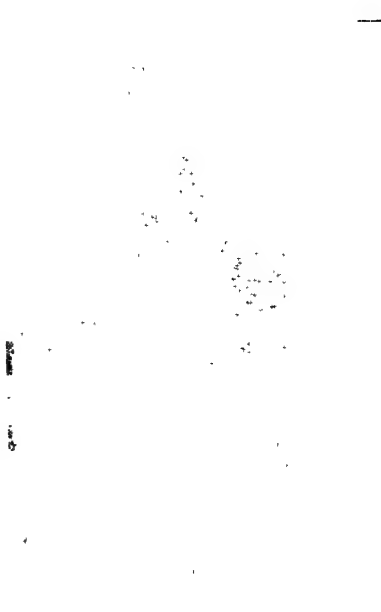


Fig. 160. Gigantism  
Right—man of average height; left—  
adolescent



## EPIPHYSIS CEREBRI

The epiphysis cerebri is a small body, resembling a pine cone and is therefore also called the **pineal gland**. It is located in the cranial cavity behind the thalami between the superior colliculi. It attains its greatest development in childhood; in the adult it consists almost entirely of connective tissue.

The function of this gland is still unknown. Some facts indicate that it inhibits premature development of the sex glands.

## THYROID GLAND

The thyroid gland (*glandula thyreoidea*) is situated on the anterior surface of the neck and weighs from 30 to 60 g (Fig. 161). It consists of *right* and *left lobes* and an *isthmus*; the lobes adhere to the larynx and the trachea, while the isthmus adheres to the second, third and fourth cartilages of the trachea. Sometimes the isthmus

gives off a *pyramidal lobe* which extends upward. Inside the gland there are small vesicles or follicles with walls of glandular epithelium. The cavities of the vesicles are filled with a viscous (colloid) substance which contains *thyroxin* and *triiodothyronine*, the hormones of the thyroid gland, which contain iodine. Triiodothyronine is several times more active than thyroxin. These hormones influence metabolism; the growth and development of the organism, the excitability of the nervous system, etc.

**Hyperfunction of the thyroid gland** gives rise to a disease called *Basedow's disease* (after the physician who first described it) or *exophthalmic goitre*. This disease is characterized by increased metabolism, excitability of the nervous system, and rapid fatigue. The symptoms are an enlargement of the thyroid gland (goitre), bulging eyes (exophthalmos) (Fig. 162) and a faster heart rate (tachycardia). A person suffering from this disease loses

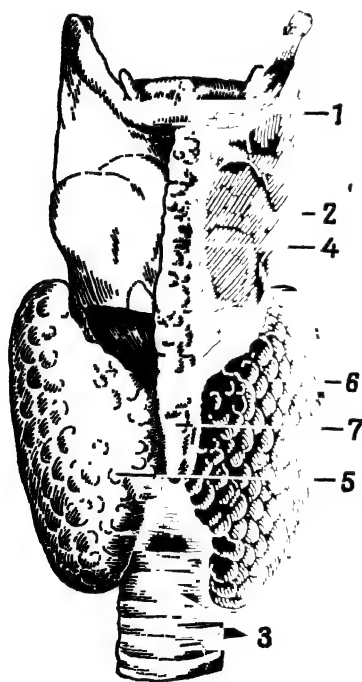
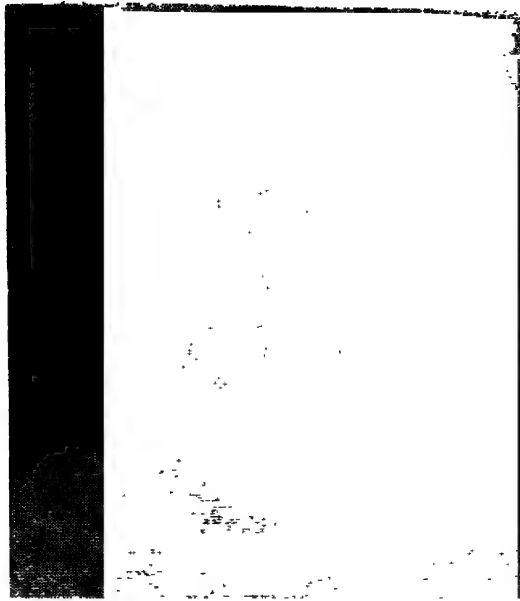
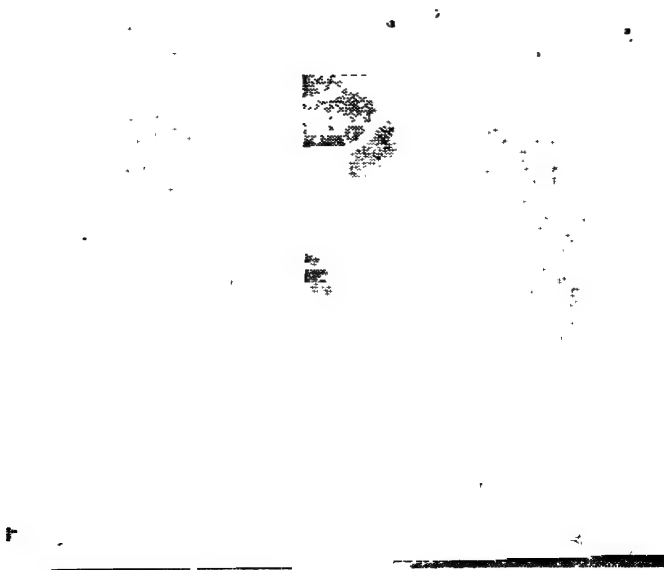


Fig. 161. Thyroid gland  
1—hyoid bone; 2—thyroid cartilage; 3—trachea; 4—pyramidal lobe; 5—right lobe; 6—left lobe; 7—isthmus



**Fig. 162. Woman with exophthalmic goitre (Basedow's disease)**



**Fig. 163 Treatment of cretinism with thyroid preparations  
12-year-old girl; right—before treatment; left—six months after treatment**

weight, becomes irritable, develops tremor of the hands, and sweats profusely.

**Hypofunction of the thyroid gland** is also accompanied by changes throughout the organism.

**Myxoedema** and **cretinism** are the diseases caused by hypofunction of the thyroid. *Myxoedema* (from the words *myxa*—mucus, and *oedema*—swelling) is characterized by diminished metabolism, retarded growth and development, impaired mental activity, a swelling of certain part of the skin and other changes.

*Cretinism* (feeble-mindedness) (Fig. 163) occurs when the thyroid gland functions poorly or atrophies in childhood. This disease is characterized by retarded growth (dwarfism), disproportionate sizes of the various parts of the body (large head, short extremities), extremely low mentality, underdevelopment of the secondary sex characters, and other changes.

A disease known as *simple* or *endemic goitre* is widespread in some mountainous regions (Switzerland, Germany and other countries). This disease is caused by lack of iodine in drinking water (iodine is necessary for the formation of thyroxin). In simple goitre the epithelium of the thyroid gland attains excessive growth and the gland is sometimes greatly enlarged. In places where simple goitre is widespread small doses of iodine are administered prophylactically. Iodine may be added to the common salt used in food.

## PARATHYROID GLANDS

The parathyroid glands are small oval bodies located on the posterior surface of the thyroid gland. There are **four parathyroid glands**—**two superior and two inferior**, each weighing about 0.05 g. The function of the parathyroid glands is not clear. A hormone called *parathormone* has been isolated from these glands. The parathyroids have been found to influence calcium and phosphorus metabolism in the organism. Removal of these glands leads to a sharp decrease of calcium in the blood plasma. This condition is characterized by intense spasms of many or all of the muscles and is called *tetany*. The animal dies from asphyxiation due to spasm of the respiratory muscles. Some morbid conditions accompanied by muscular spasm are considered to be due to hypofunction of the parathyroid glands. These conditions include cases of tetany in children and in pregnant women. Hypofunction of the parathyroids is also held responsible for disturbances in calcium metabolism leading to tooth decay in young people. It is interesting to note that the effect of parathormone on the organism is similar to that of vitamin D.

## THYMUS

The thymus (*glandula thymus*) is located in the thoracic cavity behind the manubrium of the sternum (Fig. 164). It consists of two lobes joined by a *layer of connective tissue*. The substance of the gland is composed of small lobules consisting of cortical and medullary layers. The cortical substance contains a large number of lymphocytes. The medullary substance contains fewer lymphocytes but has so-called Hassall's corpuscles which consist of squamous epithelial cells; these corpuscles are generally thought to perform a secretory function.

The activity of the thymus manifests itself mainly in childhood. The gland attains its greatest development between 11 and 15 years of age, when it weighs about 35 g. The thymus of a newborn child weighs about 13 g. From the time of sexual maturity the substance of the gland is gradually replaced by adipose tissue, so that in the adult the gland consists of adipose tissue with only a small portion of glandular tissue. The function of the thymus is not clear. Hormone has been isolated from this gland. It is believed that in childhood, before sexual maturity, the thymus inhibits the maturation of the sex glands. Experiments on animals involving the removal of the thymus resulted in various changes, particularly in the structure of the bones (the bones became soft and fragile) and retarded growth.

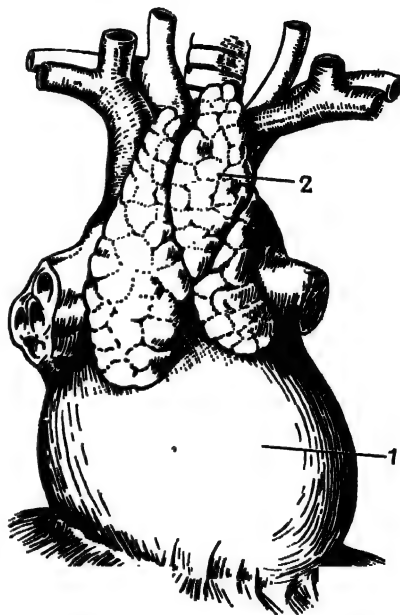


Fig. 164. Thymus of 12-year-old boy (anterior view)  
1—pericardium; 2—thymus

## ISLET PART OF THE PANCREAS

The pancreas is a gland with both external and internal secretion. In addition to the pancreatic juice, which is delivered to the duodenum, the gland produces hormones—insulin\* and glucagon. The

\* The word insulin comes from the Latin word *insula*—island.

glandular tissue which secretes the hormones forms so-called islets of Langerhans.

*Insulin* influences carbohydrate metabolism, i.e., it helps to oxidize carbohydrates in the tissues and to deposit (synthesize) glycogen in the liver and muscles. Hypofunction of the pancreas accompanied by a decrease in the secretion of insulin gives rise to *diabetes mellitus*. In this disease the tissues cannot assimilate sugar normally and the liver fails to store glycogen. As a result the sugar content in the blood increases to 0.3-0.8 per cent (sometimes as high as one per cent) instead of the normal 0.1-0.12 per cent. This condition is called *hyperglycaemia*. An invariable symptom of diabetes mellitus is the presence of sugar in the urine (*glycosuria*). This condition is accompanied by the passage of large quantities of urine (8-10 litres in 24 hours) and increased thirst.

The disturbances in carbohydrate metabolism in cases of diabetes mellitus are associated with changes in fat and protein metabolism. The fats in the organism are only partly oxidized, not to end products, i.e., water and carbon dioxide, but to intermediate substances—ketone bodies (acetone, etc.). Some of the proteins ingested by the organism are transformed into intermediate acid products. The products of incomplete fat and protein metabolism are harmful and may poison the organism causing dyspnoea, cardiac weakness and loss of consciousness. This state is called *diabetic coma* and is dangerous to life.

Some conditions are characterized by increased insulin secretion (for example, in tumours of the pancreas) and are accompanied by a decrease in blood sugar, which may give rise to dangerous phenomena such as convulsions, drop in temperature and loss of consciousness. This state is called *insulin* or *hypoglycaemic shock*.

Administration of insulin is also accompanied by a decrease in the blood sugar.

*Glucagon* causes glycogenolysis, i.e., its effect is opposite to that of insulin.

It is believed that the pancreas also secretes other active substances—*padutin* and *lipocaic*.

*Padutin* (kallikrein) reduces blood pressure by causing dilation of small blood vessels in various organs. *Lipocaic* regulates fat metabolism in the liver; in the absence of this hormone the process of fat combustion in the liver is disturbed and a fatty liver is formed.

## ADRENALS

The adrenals or suprarenal glands (glandulae suprarenales) (see Fig. 86) are located in the lumbar region near the superior poles of the kidneys. The adrenals are a paired organ; each adrenal weighs about 12 g, is triangular or crescent-shaped, and has two layers.

The outer layer is called the **cortical substance** and the inner layer is called the **medullary substance**. The cortical substance is coloured a pale yellow, and in its turn consists of three layers—granular, fascicular and reticular. These layers differ from each other in microscopic structure and secrete different hormones. The medullary substance is of a darker colour.

The cortical substance produces several hormones known under the common name of **corticosteroids**. The main corticosteroids are aldosterone, hydrocortisone, corticosterone and androgens. The hormones of the adrenal cortex help to regulate metabolism, eliminate muscular fatigue, and enhance the resistance of the organism to various harmful factors (bacterial toxins, low temperature), etc. For example, *aldosterone* regulates mineral metabolism, retains sodium in the organism and helps to eliminate potassium; *hydrocortisone* and *corticosterone* influence protein, fat and carbohydrate metabolism and maintain basal metabolism at a normal level. The action of the *androgens* closely resembles that of the sex hormones and is concerned in sexual development.

**Hypofunction of the adrenals**, especially of the cortical layer, causes a severe disease called *Addison's disease* (after the physician who was the first to describe it). This disease is characterized by disturbance in metabolism, loss of weight, loss of appetite, drop in blood pressure and other phenomena. A bronzing of the patient's skin is one of the characteristic signs of the disease. The disease used to be fatal, but today patients are treated with an extract from the cortical substance of the adrenals or with hormones, and the development of the disease is prevented.

**Hyperfunction of the cortical layer of the adrenals**, for example in cases of adrenal tumours, is accompanied by changes in the genital system. In children this condition may result in premature sexual maturation, and in women it may result in secondary male sex characters (beard, moustache, etc.).

According to a theory advanced by Selye, the adrenocorticohypophyseal system plays a very important role in helping the organism to defend itself against the action of particularly harmful stimuli—infection, intoxication, burns, trauma, etc. If such harmful influences are present the hypophysis secretes large amounts of the adrenocorticotrophic hormone which influences the adrenal cortex through the blood. As a result, the adrenal cortex increases its secretion of hormones and the organism is able to adapt itself.

The medullary substance of the adrenals secretes epinephrine.

*Epinephrine* is one of the best-known hormones. It may be prepared synthetically and is widely used in medicine. It has been established by numerous investigations that the action of epinephrine is similar to that of the sympathetic division of the nervous system.

For example, epinephrine increases the heart rate and intensifies cardiac contractions, causes contraction of the walls of the blood vessels (except the vessels of the heart and brain), reduces intestinal peristalsis, causes contraction of the muscles of the uterus and the dilator pupillae muscle, and relaxes the muscles of the bronchial walls, etc. The intensification of cardiac contractions and the constriction of blood vessels causes the blood pressure to rise. Epinephrine helps to enhance the working capacity of the skeletal muscles.

In emotional states, such as rage or fear, the activity of the medullary substance of the adrenals increases; this is accompanied by increased secretion and delivery into the blood of epinephrine. These states are characterized by pallor of the skin, a faster heart rate and other phenomena associated with the action of epinephrine.

Epinephrine influences carbohydrate metabolism, i.e., it helps to transform the glycogen of the liver into glucose, which is delivered to the blood. Consequently, epinephrine and insulin exert opposing influences on carbohydrate metabolism and thereby help to keep the content of glucose in the blood relatively constant.

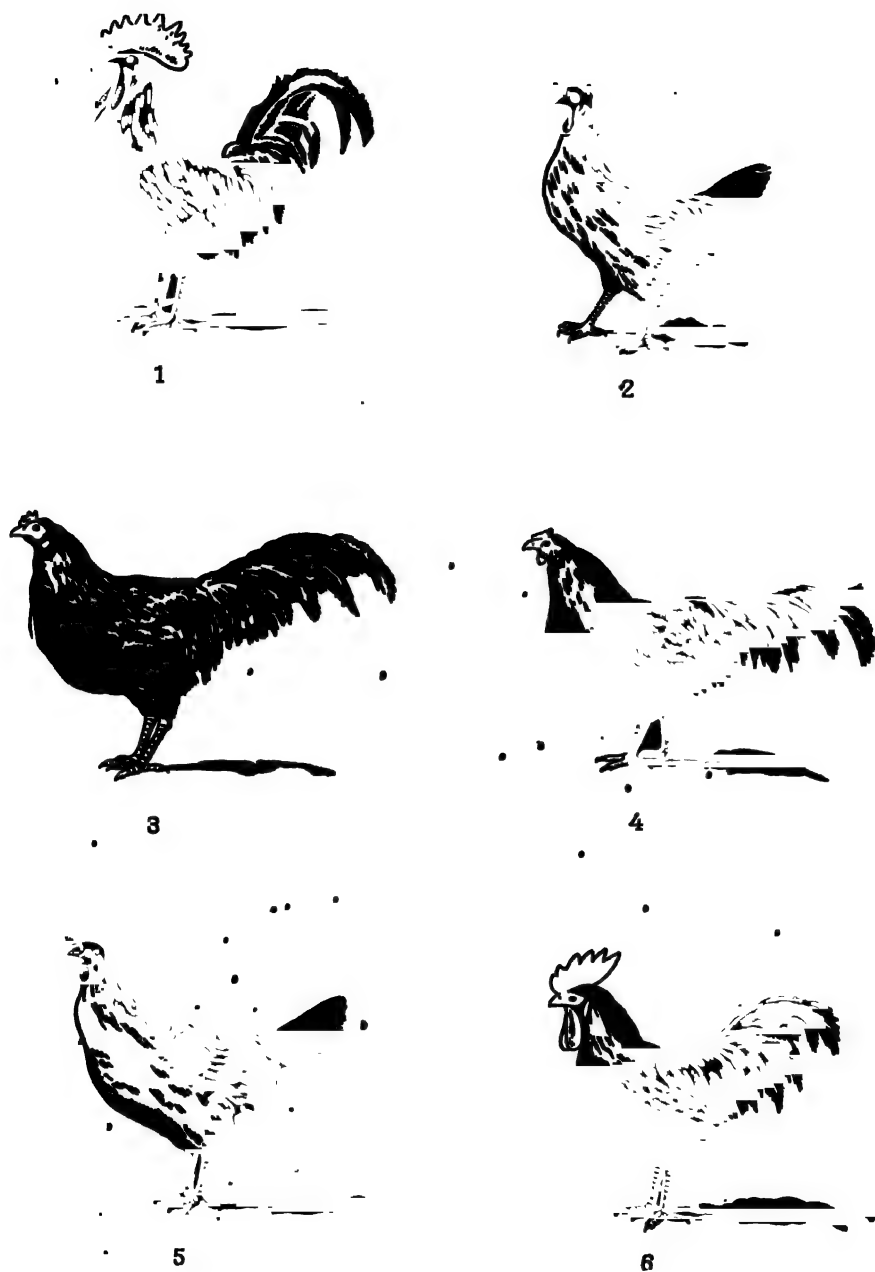
### INCRETORY FUNCTION OF THE SEX GLANDS

The sex glands, the testes and ovaries, are organs in which the germ cells develop; they are also endocrine glands. These glands internally secrete sex hormones which are delivered into the blood. The sex hormones influence various functions. For example, sexual maturation of the organism is associated with the development of the sex glands and the secretion of sex hormones. Sexual maturation implies the development of the primary and appearance of the secondary sex characters; this occurs from 12 to 18 years of age.

The primary sex characters include the particular structures of the sex glands and genitalia of males and females. The secondary sex characters involve many characteristics of the structure and function of the organism which distinguish one sex from the other. Such characters include the differences in build between male and female (differences in the breadth of the pelvis and shoulders, differences in the shape of the thorax and skull, etc.), the distribution of hair over the body (beard, moustache, and hair on the chest and abdomen in men), the different degrees of development of the larynx and the concomitant differences in the timbre of the voice.

The sex hormones also influence metabolism and mentality. It should be remembered that all the processes affected by the sex hormones are also regulated by other endocrine glands and are under control of the nervous system. There are male and female sex hormones.

The male sex hormones, *testosterone* and *androsterone*, are produced in the testes. They influence the sexual development of the male,



**Fig. 165. Change of sex**

**1—normal rooster; 2—normal hen; 3—castrated rooster; 4—castrated hen; 5—castrated rooster with transplanted hen's ovaries; 6—castrated hen with transplanted rooster's testes**



excite activity of the sex organs and the sex drive, and participate in the regulation of metabolism and other functions of the organism.

The female sex hormones, estrone or folliculin and progesterone (lutein), are produced in the ovaries, the former in the follicles and the latter in the corpus luteum. *Estrone* influences the sexual maturation of the female organism and the development of the mammary glands, and regulates menstruation. *Progesterone* is called the *hormone of pregnancy* because it influences the normal course of pregnancy. For example, progesterone controls the periodic changes in the mucous membrane of the uterus, which precede the onset of pregnancy; it also delays the maturation of follicles and is responsible for the changes in the mammary glands during pregnancy. Experiments on animals have shown that if the corpus luteum in which lutein is formed is destroyed, pregnancy will not take place. The female sex hormones, like the male sex hormones, participate in the regulation of metabolism.

At 45-50 years of age the incretory function of the ovaries gradually ceases. At the same time maturation of the follicles stops, the follicles atrophy, menstruation ceases, and there are changes in the activity of other endocrine glands. This period is called the menopause; it is often characterized by various morbid phenomena (increased nervous excitability, headaches, sometimes insomnia, etc.)

The role of the sex hormones is particularly vividly demonstrated in animals whose sex glands have been removed (castration) or transplanted. Cattle are castrated for fattening. Castrated animals lose their sexual desire, their metabolism diminishes and a large amount of fat is deposited in their bodies. Some people who for some reason or other had both sex glands removed have been observed. If such an operation is carried out in childhood the sex organs and the secondary sex characters cease to develop. Removal of the sex glands in adults results in changes in the secondary sex characters, and reduced metabolism accompanied by deposition of fat.

Experiments conducted on hens and roosters on the mutual transplantation of sex glands ("change of sex") are of some interest. Hens which had their ovaries removed and testes grafted, began to resemble roosters in appearance and behaviour. The appearance of castrated roosters with engrafted ovaries also changed (Fig. 165).

In completing the discussion of the endocrine glands it must once again be emphasized that hormone secretion depends on nervous regulation. For example, the increased secretion of epinephrine in various emotional states (rage, fear) shows that the cerebral cortex exerts an influence on the function of the adrenals.

The endocrine glands in their turn affect the state of the nervous system (impairment of the mental faculties in cases of thyroid hypofunction, increased nervous excitability in thyroid hyperfunction, changes in the activities of the system during the menopause, etc.).

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